

**STUDIES ON BIOEFFICACY, SAFETY, PHYTOTOXICITY AND
ARTHROPOD DIVERSITY OF PYRIDINE DERIVATIVE 20 SC
IN TOMATO AND RICE**

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CHAPTER VI

SUMMARY

Studies were conducted to evaluate pyridine derivative 20 SC for its bioefficacy against fruit borer and serpentine leafminer in tomato as well as rice stem borer and leaf folder, its safety to natural enemies and beneficial insects, phytotoxicity, impact on arthropod biodiversity in tomato and rice ecosystems and molecular characterization of ryanodine receptor in target pests and non- target organisms. The salient findings of the studies are summarized hereunder.

- Two rounds of foliar application of pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ was effective in reducing the damage caused by *Helicoverpa armigera* Hubner and *Liriomyza trifolii* (Burgess).
- Pyridine derivative 20 SC @ 50 and 60 g a.i. ha⁻¹ applied thrice at 14 days interval significantly reduced the damage caused by stem borer (52.03 - 54.68 and 47.79 - 52.80 %, respectively) and leaf folder (35.74 - 40.72 and 26.90 - 31.25 %, respectively) in first and second season.
- Pyridine derivative 20 SC at all the test doses slightly reduced the natural enemies viz., coccinellids, spiders in tomato; spiders, mirids and rove beetles in rice immediately after the spraying. Though there was a sudden decline in the population, it started increasing gradually ten days after spraying.
- Foliar application of pyridine derivative 20 SC (60, 120 and 240 g a.i. ha⁻¹) in tomato and rice did not cause any phytotoxic symptoms.
- Pyridine derivative 20 SC (60 g a.i. ha⁻¹) recorded maximum tomato yield of 38.08 t ha⁻¹ with tomato hybrid (US 3140) and 42.20 t ha⁻¹ (Mahalakshmi) in the first and second season, respectively.
- In rice, yield varied from 4.27 to 4.92 t ha⁻¹ in first season and 3.62 to 4.30 t ha⁻¹ in second season using CO (R) 48 variety with increased yield per cent over control in all the pyridine derivative 20 SC treated plots.

- A total of 2,760 arthropod individuals belonging to 48 families and 14 orders in both sprayed and unsprayed tomato field were collected. Unsprayed tomato showed higher species richness, abundance and distribution at ordinal, familial, generic and species level than sprayed tomato field.
- The species richness indices based on Species number, Fishers Alpha index, Margalef's D index, Q Statistic, Brillouin diversity index and Shannon-Weiner index and dominance indices viz., Simpson's index, McIntosh index and Berger Parker index, the index values were higher in unsprayed tomato than sprayed field.
- Beta diversity indices based on ordinal, familial, generic level and species level indicated higher index values in sprayed field than unsprayed tomato field.
- A total of 5,095 individuals belonging to 90 species, 84 genera, 54 families and 11 orders were recorded in rice ecosystem from two classes viz., Insecta and Arachnida.
- Hemiptera and Hymenoptera were predominant in terms of individuals of exopterygota and endopterygota, respectively. Under Arachnida, Araneae was the most dominant order with maximum individuals belong to Tetragnathidae.
- Biodiversity survey revealed the presence of spiders viz., *Argiope* sp., *Neoscona* sp., *Clubiona* sp., *Lycosa* sp., *Pardosa* sp., *Pardosa birmanica* Simon, *Oxyopes javanus* Thorell, *Oxyopes* sp., *Peucetia viridana* Hentz, *Philodromus rufus* Walckenaer, *Plexippus paykulli* Audouin, *Tetragnatha javana* Thorell, *Tetragnatha* sp., *Tylorida striata* Thorell and *Thomisus* sp.
- The biodiversity indices revealed that based on familial level, Species richness indices viz., species number, Fishers alpha index, Q Statistic, Margelef D index, Shannon - Weiner index and Brillouin diversity index, the value was highest in unsprayed field and it was maximum in the month of October.
- Dominance indices viz., Simpson's index and McIntosh index, the values were highest during the month of October and lowest during the month of December based on ordinal, familial, generic and species level.
- Pyridine derivative 20 SC (50 and 40 g a.i. ha⁻¹) was safer to *Trichogramma chilonis* Ishii which recorded 46.67 – 55.00 per cent adult emergence and 79.67 - 82.67 per cent parasitisation, respectively.
- Pyridine derivative 20 SC (50 and 40 g a.i. ha⁻¹) caused 26.67 and 16.67 and 36.67 and 23.33 per cent mortality at 24 and 48 HAT, respectively and was least toxic to larval parasitoid, *Bracon hebetor* Say.
- *Chrysoperla zastrowi sillemi* (Esben - Petersen) eggs treated with pyridine derivative 20 SC (50 and 40 g a.i. ha⁻¹) recorded 79.91 and 83.22 per cent hatching. All the doses of pyridine derivative 20 SC (60, 50 and 40 g a.i. ha⁻¹) caused less than 50 per cent mortality to the grubs by dry film method and was safer to the immature stages of *C. zastrowi sillemi*
- Pyridine derivative 20 SC @ 50 and 40 g a.i. ha⁻¹ recorded moderate toxicity to grubs and adults of *Cheilomenes sexmaculata* (Fabricius).
- *In vitro* contact toxicity bioassay with pyridine derivative 20 SC @ 60, 50 and 40 g a.i. ha⁻¹ exhibited less toxicity to worker dammer bees, little bees, rock bees and Indian bees.
- Pyridine derivative 20 SC at all tested doses weakly affected the growth of *Trichoderma viride* Persoon, *Pseudomonas fluorescens* Migula and *Beauveria Bassiana* Balsamo.
- The computational protein structure prediction and phylogenetic tree analysis resulted that RyR in different insect species viz., *H. armigera*, *Apis mellifera* Linnaeus, *Tribolium castaneum* (Herbst), *Bactrocera cucurbitae* (Coquillett) and *Sogatella furcifera* (Horvath) showed greater variation among the structures.

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Table 2. Effect of pyridine derivative 20 SC against tomato fruit borer damage (Location: Thennamanallur - I season)

Treatment	Doseg a.i.ha ⁻¹	Per cent fruit damage												Pooled Mean	%ROC
		I spray						II spray							
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean			
Pyridine derivative 20 SC	40	12.25 (20.46)	11.75 (20.04) ^{ab}	8.16 (16.59) ^b	9.85 (18.28) ^{bc}	10.70 (19.08) ^{bc}	10.12	10.03 (18.46) ^b	7.90 (16.31) ^{bc}	8.23 (16.67) ^b	9.50 (17.78) ^{bc}	8.91	9.51	50.12	
Pyridine derivative 20 SC	50	12.65 (20.82)	11.64 (19.94) ^{ab}	7.50 (15.88) ^{ab}	8.91 (17.35) ^{ab}	9.77 (18.18) ^{ab}	9.45	9.50 (17.93) ^{ab}	6.94 (15.27) ^{ab}	7.40 (15.78) ^{ab}	8.36 (16.55) ^{ab}	8.05	8.75	54.13	
Pyridine derivative 20 SC	60	11.22 (19.23)	10.91 (19.29) ^a	7.09 (15.44) ^a	8.11 (16.51) ^a	9.01 (17.44) ^a	8.78	8.60 (17.02) ^a	5.79 (13.92) ^a	6.63 (14.90) ^a	6.63 (14.91) ^a	6.91	7.85	58.88	
Chlorantraniliprole 20 SC	30	12.24 (20.45)	12.06 (20.31) ^b	9.22 (17.67) ^c	10.55 (18.95) ^c	11.39 (19.72) ^{cd}	10.80	11.73 (20.03) ^c	8.68 (17.12) ^{cd}	9.72 (18.16) ^c	11.97 (20.24) ^c	10.52	10.66	44.10	
Novaluron 10 EC	75	11.46 (19.78)	11.31 (19.64) ^{ab}	10.01 (18.44) ^c	10.76 (19.15) ^c	12.12 (20.37) ^{cd}	11.05	12.48 (20.69) ^c	10.04 (18.39) ^d	9.58 (18.02) ^c	11.81 (20.09) ^c	10.98	11.01	42.28	
Untreated check	-	11.31 (19.52)	14.58 (22.43) ^f	16.09 (23.64) ^f	17.50 (24.73) ^f	18.81 (25.70) ^f	16.74	19.96 (26.53) ^f	21.88 (27.88) ^f	21.82 (27.84) ^f	21.98 (27.96) ^f	21.41	19.08	-	

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 3. Effect of pyridine derivative 20 SC on *Helicoverpa armigera* Hubner larvae in tomato (Location: Thennamanallur - I season)

Treatment	Doseg a.i.ha ⁻¹	Number of larva five plant ⁻¹												Pooled Mean	%ROC
		I spray						II spray							
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean			
Pyridine derivative 20 SC	40	8.80 (3.05)	4.80 (2.30) ^a	1.00 (1.22) ^b	1.40 (1.38) ^b	1.80 (1.52) ^b	2.25	0.60 (1.05) ^{ab}	0.20 (0.84) ^a	0.60 (1.05) ^b	1.20 (1.30) ^b	0.65	1.45	87.54	
Pyridine derivative 20 SC	50	9.40 (3.15)	4.00 (2.12) ^a	0.40 (0.95) ^a	0.80 (1.14) ^b	1.00 (1.22) ^a	1.55	0.40 (0.95) ^a	0.00 (0.72) ^a	0.20 (0.84) ^{ab}	0.80 (1.14) ^b	0.36	0.95	91.82	
Pyridine derivative 20 SC	60	8.40 (2.98)	3.20 (1.92) ^a	0.20 (0.84) ^a	0.60 (1.05) ^a	0.60 (1.05) ^a	1.15	0.20 (0.84) ^a	0.00 (0.72) ^a	0.00 (0.71) ^a	0.20 (0.84) ^a	0.11	0.63	94.60	
Chlorantraniliprole 20 SC	30	9.20 (3.11)	6.00 (2.55) ^b	1.20 (1.30) ^b	1.80 (1.52) ^b	2.00 (1.58) ^b	2.75	1.00 (1.22) ^b	0.20 (0.85) ^a	0.40 (0.95) ^b	0.80 (1.14) ^b	0.61	1.68	85.60	
Novaluron 10 EC	75	8.60 (3.02)	7.60 (2.85) ^c	2.60 (1.76) ^c	3.80 (2.07) ^c	3.60 (2.02) ^c	4.40	2.20 (1.64) ^c	1.40 (1.38) ^b	1.80 (1.52) ^c	2.20 (1.64) ^c	1.90	3.15	72.96	
Untreated check	-	9.20 (3.11)	10.20 (3.27) ^d	12.20 (3.56) ^d	10.80 (3.36) ^d	12.60 (3.62) ^d	11.85	11.20 (3.42) ^d	12.00 (3.54) ^d	11.80 (3.51) ^d	12.40 (3.59) ^d	11.85	11.65	-	

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 4. Effect of pyridine derivative 20 SC against serpentine leafminer damage in tomato (Location: Thennamanallur - I season)

Treatment	Doseg a.i.ha ⁻¹	Per cent leaf damage plant ⁻¹														Pooled Mean	%ROC
		I spray							II spray								
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT		
Pyridine derivative 20 SC	40	30.54 (33.54)	29.19 (32.70) ^{ab}	28.21 (32.08) ^{bc}	28.04 (31.97) ^{bc}	29.46 (32.87) ^{bc}	28.73	29.09 (32.64) ^{bc}	28.50 (32.26) ^{bc}	28.01 (31.95) ^{bc}	27.85 (31.85) ^{bc}	28.36	28.55	20.34			
Pyridine derivative 20 SC	50	31.07 (33.87)	28.86 (32.49) ^{ab}	27.51 (31.63) ^{ab}	27.34 (31.52) ^{ab}	28.08 (31.99) ^{ab}	27.95	27.93 (31.90) ^{ab}	26.91 (31.25) ^{ab}	26.48 (30.97) ^{ab}	26.33 (30.87) ^{ab}	26.91	27.43	23.45			
Pyridine derivative 20 SC	60	30.86 (33.75)	27.94 (31.91) ^a	26.01 (30.66) ^a	25.86 (30.55) ^a	26.74 (31.13) ^a	26.64	26.43 (30.94) ^a	25.42 (30.27) ^a	24.87 (29.91) ^a	24.73 (29.81) ^a	25.36	26.00	27.45			
Chlorantraniliprole 20 SC	30	31.25 (33.97)	30.06 (33.25) ^b	28.93 (32.54) ^c	29.42 (32.84) ^c	30.35 (33.43) ^c	29.69	30.17 (33.32) ^c	30.00 (33.21) ^c	29.67 (33.00) ^c	29.50 (32.90) ^c	29.84	29.76	16.95			
Novalluron 10 EC	75	30.69 (33.64)	30.06 (32.99) ^b	29.58 (32.95) ^{bc}	28.75 (32.43) ^{bc}	30.12 (33.28) ^c	29.64	30.34 (33.42) ^c	29.56 (32.93) ^c	29.23 (32.73) ^c	29.06 (32.62) ^c	29.55	29.60	17.41			
Untreated check	-	31.14 (33.91)	32.88 (34.99) ^f	33.46 (35.34) ^g	34.55 (36.00) ^d	34.74 (36.12) ^d	33.91	35.33 (36.46) ^d	37.42 (37.71) ^d	38.56 (38.39) ^d	39.74 (39.08) ^d	37.76	35.84	-			

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 5. Effect of pyridine derivative 20 SC on serpentine leafminer maggots in tomato (Location: Thennamanallur - I season)

Treatment	Doseg a.i.ha ⁻¹	Number of maggots plant ⁻¹														Pooled Mean	%ROC
		I spray							II spray								
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT		
Pyridine derivative 20 SC	40	8.15 (2.94)	2.25 (1.86) ^{bc}	2.25 (1.66) ^{bc}	2.50 (1.73) ^c	2.85 (1.83) ^c	2.64	1.70 (1.48) ^c	1.45 (1.40) ^c	1.70 (1.48) ^b	2.00 (1.58) ^{bc}	1.71	2.18	77.78			
Pyridine derivative 20 SC	50	7.70 (2.86)	2.20 (1.64) ^{ab}	1.60 (1.45) ^{ab}	1.90 (1.55) ^b	2.30 (1.67) ^b	2.00	1.25 (1.32) ^b	0.95 (1.20) ^b	1.15 (1.28) ^{ab}	1.55 (1.43) ^{ab}	1.23	1.61	83.52			
Pyridine derivative 20 SC	60	8.05 (2.92)	1.80 (1.52) ^a	1.05 (1.24) ^a	1.30 (1.34) ^a	1.60 (1.45) ^a	1.44	0.70 (1.10) ^a	0.60 (1.05) ^a	0.75 (1.12) ^a	1.35 (1.36) ^a	0.85	1.14	88.31			
Chlorantraniliprole 20 SC	30	8.55 (3.01)	3.30 (1.95) ^c	2.50 (1.73) ^{cd}	2.70 (1.79) ^c	3.15 (1.91) ^c	2.91	1.80 (1.52) ^c	1.35 (1.36) ^{bc}	1.65 (1.47) ^b	2.00 (1.58) ^c	1.70	2.31	76.44			
Novalluron 10 EC	75	7.85 (2.89)	4.70 (2.28) ^d	3.20 (1.92) ^d	3.45 (1.99) ^d	3.90 (2.10) ^d	3.81	2.75 (1.80) ^d	2.35 (1.69) ^d	2.60 (1.76) ^c	2.95 (1.86) ^d	2.66	3.24	66.42			
Untreated check	-	8.45 (2.99)	8.75 (3.04) ^e	9.05 (3.09) ^e	9.30 (3.13) ^e	9.70 (3.19) ^e	9.20	9.95 (3.23) ^e	10.10 (3.26) ^e	10.60 (3.33) ^d	10.85 (3.37) ^e	10.38	9.79	-			

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x + 0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 6. Effect of pyridine derivative 20 SC on coccinellids in tomato (Location: Thennamanallur - I season)

Treatment	Doseg a.i.ha ⁻¹	Number ten plants ⁻¹												Pooled Mean
		I spray						II spray						
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean		
Pyridine derivative 20 SC	40	6.25 (2.60)	3.50 (2.00) ^{bc}	3.50 (2.00) ^b	3.75 (1.94) ^{bc}	4.25 (2.18) ^b	3.75	3.50 (2.00) ^c	3.00 (1.87) ^b	4.00 (2.12) ^b	4.75 (2.29) ^b	3.81	3.78	
Pyridine derivative 20 SC	50	6.25 (2.60)	3.00 (1.87) ^{cd}	3.00 (1.87) ^{cd}	3.25 (2.06) ^{bc}	3.50 (2.00) ^{bc}	3.19	3.25 (1.94) ^{cd}	3.00 (1.87) ^b	3.50 (2.00) ^{bc}	4.50 (2.24) ^b	3.69	3.38	
Pyridine derivative 20 SC	60	5.50 (2.45)	3.00 (1.87) ^{cd}	2.25 (1.66) ^d	2.50 (1.73) ^{cd}	3.50 (2.00) ^{bc}	2.81	2.00 (1.58) ^e	2.00 (1.58) ^{cd}	2.75 (1.80) ^{cd}	3.50 (2.00) ^c	2.69	2.69	
Chlorantraniliprole 20 SC	30	5.75 (2.50)	2.50 (1.73) ^d	3.00 (1.87) ^{bc}	2.75 (1.73) ^e	3.25 (1.94) ^c	2.88	2.50 (1.73) ^{de}	2.75 (1.80) ^c	2.25 (1.94) ^{cd}	3.75 (2.06) ^c	2.00	2.97	
Novaluron 10 EC	75	6.00 (2.55)	4.00 (2.12) ^b	2.75 (1.80) ^c	3.25 (1.94) ^b	3.50 (2.00) ^{bc}	3.38	4.50 (2.24) ^b	3.50 (2.00) ^{bc}	3.00 (1.87) ^{cd}	3.75 (2.06) ^c	3.69	3.53	
Untreated check	-	6.00 (2.55)	6.50 (2.65) ^a	6.75 (2.69) ^a	7.25 (2.78) ^a	6.25 (2.60) ^a	6.69	7.00 (2.74) ^a	7.50 (2.83) ^a	6.25 (2.60) ^a	7.00 (2.74) ^a	6.94	6.81	

PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 7. Effect of pyridine derivative 20 SC on spiders in tomato (Location: Thennamanallur - I season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten plants ⁻¹												Pooled Mean
		I spray						II spray						
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean		
Pyridine derivative 20 SC	40	9.00 (3.08)	6.75 (2.69) ^b	5.75 (2.50) ^b	6.00 (2.55) ^b	7.00 (2.74) ^b	6.38	5.00 (2.35) ^c	5.25 (2.40) ^b	6.75 (2.69) ^b	7.75 (2.87) ^b	6.19	6.29	
Pyridine derivative 20 SC	50	8.75 (3.04)	4.75 (2.69) ^c	5.50 (2.45) ^{bc}	5.25 (2.40) ^c	6.75 (2.69) ^{bc}	5.56	5.75 (2.50) ^b	5.00 (2.35) ^b	5.50 (2.45) ^c	7.50 (2.83) ^b	5.94	5.75	
Pyridine derivative 20 SC	60	8.50 (3.00)	4.25 (2.18) ^c	4.75 (2.29) ^{cd}	4.75 (2.29) ^d	6.00 (2.55) ^d	4.94	4.75 (2.29) ^{cd}	4.25 (2.18) ^c	5.50 (2.45) ^c	6.25 (2.60) ^c	5.19	5.07	
Chlorantraniliprole 20 SC	30	8.25 (2.96)	3.00 (1.87) ^d	3.75 (2.06) ^e	5.00 (2.35) ^{cd}	6.25 (2.60) ^{cd}	4.50	3.50 (2.00) ^e	3.75 (2.06) ^c	4.50 (2.24) ^d	6.00 (2.55) ^c	4.44	4.47	
Novaluron 10 EC	75	8.50 (3.00)	4.50 (2.24) ^c	4.25 (2.18) ^{de}	5.25 (2.40) ^c	6.50 (2.65) ^{bcd}	5.13	4.25 (2.18) ^d	4.00 (2.12) ^c	5.25 (2.40) ^c	6.00 (2.55) ^c	4.88	5.01	
Untreated check	-	8.25 (2.96)	9.00 (3.08) ^a	8.50 (3.00) ^a	8.00 (2.92) ^a	8.25 (2.96) ^a	8.44	8.00 (2.92) ^a	7.50 (2.83) ^a	8.00 (2.92) ^a	9.75 (3.20) ^a	8.31	8.38	

PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 8. Effect of pyridine derivative 20 SC against tomato fruit borer damage (Location: Mathampatti - II season)

Treatment	Doseg a.l.ha ⁻¹	Per cent fruit damage												Pooled Mean	%ROC
		I spray						II spray							
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean			
Pyridine derivative 20 SC	40	13.24 (21.25)	12.72 (20.89) ^{bc}	10.16 (18.58) ^{bc}	9.94 (18.38) ^{bc}	11.83 (19.92) ^b	11.16	11.17 (19.51) ^b	7.69 (16.07) ^{bc}	8.50 (16.92) ^{bc}	9.03 (17.49) ^{bc}	9.10	10.13	47.38	
Pyridine derivative 20 SC	50	12.74 (20.90)	12.15 (20.39) ^{ab}	9.04 (17.49) ^{ab}	9.89 (18.31) ^{ab}	11.37 (19.64) ^{ab}	10.61	10.90 (19.26) ^{ab}	6.62 (14.87) ^{ab}	7.11 (15.42) ^{ab}	7.72 (16.13) ^{ab}	8.09	9.35	51.44	
Pyridine derivative 20 SC	60	12.23 (20.45)	11.81 (20.10) ^a	8.50 (16.89) ^a	9.06 (17.49) ^a	10.05 (18.41) ^a	9.85	9.32 (17.73) ^a	5.94 (14.10) ^a	6.06 (14.04) ^a	6.50 (14.59) ^a	6.95	8.40	56.35	
Chlorantraniliprole 20 SC	30	13.38 (21.30)	12.86 (21.01) ^a	10.56 (18.96) ^a	11.81 (20.10) ^a	12.32 (20.43) ^b	11.89	11.21 (19.55) ^b	8.58 (17.03) ^{cd}	9.14 (17.58) ^a	9.91 (18.35) ^a	9.71	10.80	43.92	
Novalluron 10 EC	75	13.98 (21.91)	13.61 (21.65) ^d	10.74 (19.13) ^a	10.75 (19.13) ^{ab}	11.60 (19.88) ^b	11.67	11.27 (19.59) ^b	9.22 (17.67) ^d	9.43 (17.88) ^a	9.92 (18.35) ^a	9.96	10.82	43.83	
Untreated check	-	13.37 (21.44)	15.55 (23.22) ^e	16.97 (24.32) ^d	18.18 (25.24) ^d	19.09 (25.88) ^d	17.45	19.97 (26.54) ^e	20.61 (27.00) ^e	21.58 (27.67) ^d	22.09 (28.02) ^d	21.06	19.25	-	

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column means followed by a common superscripts are not significantly different by DMRT (P=0.05)

Table 9. Effect of pyridine derivative 20 SC on *Helicoverpa armigera* Hubner larvae in tomato (Location: Mathampatti - II season)

Treatment	Doseg a.l.ha ⁻¹	Number of larva ten plant ⁻¹												Pooled Mean	%ROC
		I spray						II spray							
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean			
Pyridine derivative 20 SC	40	3.80 (2.07)	1.80 (1.52) ^{bc}	1.00 (1.22) ^b	1.60 (1.45) ^b	2.60 (1.76) ^c	1.75	0.40 (0.95) ^{ab}	0.40 (0.95) ^a	0.80 (1.14) ^b	1.00 (1.22) ^{bc}	0.65	1.20	76.81	
Pyridine derivative 20 SC	50	4.20 (2.17)	1.20 (1.30) ^{ab}	0.60 (1.05) ^{ab}	1.00 (1.22) ^{ab}	1.60 (1.45) ^b	1.10	0.00 (0.71) ^a	0.20 (0.84) ^a	0.20 (0.84) ^a	0.60 (1.05) ^{ab}	0.25	0.68	86.96	
Pyridine derivative 20 SC	60	4.00 (2.12)	0.40 (0.95) ^a	0.20 (0.84) ^a	0.60 (1.05) ^a	0.80 (1.14) ^a	0.50	0.00 (0.71) ^a	0.00 (0.71) ^a	0.20 (0.84) ^a	0.20 (0.84) ^a	0.10	0.30	94.20	
Chlorantraniliprole 20 SC	30	3.80 (2.07)	2.00 (1.58) ^{bc}	1.40 (1.38) ^{bc}	1.60 (1.45) ^b	2.40 (1.70) ^c	1.85	0.80 (1.14) ^b	0.60 (1.05) ^a	0.80 (1.14) ^{bc}	1.00 (1.22) ^{bc}	0.80	1.33	74.40	
Novalluron 10 EC	75	4.20 (2.17)	3.20 (1.92) ^{cd}	2.40 (1.70) ^c	3.00 (1.87) ^c	3.80 (2.07) ^d	3.10	1.80 (1.52) ^e	1.40 (1.38) ^b	1.80 (1.52) ^e	2.00 (1.58) ^c	1.75	2.43	53.14	
Untreated check	-	4.40 (2.21)	4.20 (2.17) ^d	4.80 (2.30) ^d	5.40 (2.43) ^d	6.40 (2.63) ^e	5.20	4.60 (2.26) ^d	5.00 (2.35) ^e	5.60 (2.47) ^d	5.40 (2.43) ^d	5.15	5.18	-	

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 10. Effect of pyridine derivative 20 SC against serpentine leafminer damage in tomato (Location: Mathampatti - II season)

Treatment	Doseg a.i.ha ⁻¹	Per cent leaf damage plant ⁻¹														Pooled Mean	%ROC
		I spray							II spray								
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean					
Pyridine derivative 20 SC	40	34.70 (36.08)	34.06 (35.71) ^b	33.47 (35.35) ^b	33.68 (35.47) ^b	34.06 (35.70) ^b	33.82	33.87 (35.58) ^{bc}	33.48 (35.35) ^b	32.70 (34.88) ^{bc}	33.00 (35.06) ^{abc}	33.26	33.54	14.98			
Pyridine derivative 20 SC	50	34.34 (35.86)	33.46 (35.34) ^{ab}	32.88 (34.99) ^{ab}	32.67 (34.86) ^{ab}	33.04 (35.08) ^{ab}	33.01	32.85 (34.96) ^{ab}	32.48 (34.74) ^{ab}	32.12 (34.52) ^{ab}	32.48 (34.74) ^{ab}	32.48	32.75	17.00			
Pyridine derivative 20 SC	60	33.33 (35.26)	32.91 (35.01) ^a	32.12 (34.52) ^a	31.74 (34.29) ^a	32.11 (34.52) ^a	32.22	31.93 (34.40) ^a	31.57 (34.18) ^a	31.19 (33.95) ^a	31.63 (34.22) ^a	31.58	31.90	19.14			
Chlorantraniliprole 20 SC	30	33.69 (35.46)	33.89 (35.60) ^b	33.05 (35.09) ^b	34.22 (35.80) ^b	34.03 (35.68) ^b	33.80	33.83 (35.57) ^{bc}	33.44 (35.32) ^b	33.07 (35.10) ^{bc}	33.89 (35.60) ^{bc}	33.56	33.68	14.64			
Novaluron 10 EC	75	34.13 (35.75)	33.92 (35.62) ^b	33.51 (35.37) ^b	33.12 (35.13) ^{ab}	33.61 (35.43) ^{ab}	33.54	34.48 (35.95) ^c	33.92 (35.61) ^b	33.71 (35.49) ^c	34.31 (35.85) ^c	34.11	33.82	14.27			
Untreated check	-	35.85 (36.77)	36.86 (37.38) ^c	37.65 (37.85) ^c	38.27 (38.21) ^c	39.30 (38.82) ^c	38.02	39.66 (39.03) ^d	40.02 (39.24) ^c	41.06 (39.85) ^d	42.80 (40.86) ^d	40.89	39.45	-			

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 11. Effect of pyridine derivative 20 SC on serpentine leafminer maggots in tomato (Location: Mathampatti - II season)

Treatment	Doseg a.i.ha ⁻¹	Number of maggots plant ⁻¹														Pooled Mean	%ROC
		I spray							II spray								
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean					
Pyridine derivative 20 SC	40	9.35 (3.14)	3.30 (1.95) ^{bc}	2.80 (1.82) ^b	3.15 (1.91) ^{bc}	3.40 (1.97) ^b	3.16	2.05 (1.60) ^{bc}	1.60 (1.45) ^{bc}	1.70 (1.48) ^c	2.00 (1.58) ^b	1.84	2.50	75.02			
Pyridine derivative 20 SC	50	9.05 (3.09)	2.95 (1.86) ^{ab}	2.45 (1.72) ^b	2.75 (1.80) ^{ab}	3.10 (1.90) ^{ab}	2.81	1.70 (1.48) ^{ab}	1.25 (1.32) ^b	1.40 (1.38) ^b	1.75 (1.50) ^b	1.53	2.17	78.33			
Pyridine derivative 20 SC	60	9.25 (3.12)	2.50 (1.73) ^a	1.90 (1.55) ^a	2.20 (1.64) ^a	2.60 (1.76) ^a	2.30	1.35 (1.36) ^a	0.75 (1.12) ^a	0.95 (1.20) ^a	1.10 (1.26) ^a	1.04	1.67	83.32			
Chlorantraniliprole 20 SC	30	8.80 (3.05)	3.55 (2.01) ^{cd}	2.85 (1.83) ^b	2.95 (1.86) ^b	3.60 (2.02) ^{bc}	3.24	2.35 (1.69) ^c	1.75 (1.50) ^c	2.05 (1.60) ^d	2.45 (1.72) ^c	2.15	2.69	73.08			
Novaluron 10 EC	75	9.00 (3.08)	4.15 (2.16) ^{de}	3.70 (2.05) ^c	3.90 (2.10) ^c	4.30 (2.19) ^c	4.01	3.10 (1.90) ^d	2.25 (1.66) ^d	2.60 (1.76) ^c	2.95 (1.86) ^d	2.73	3.37	66.33			
Untreated check	-	8.75 (3.04)	9.00 (3.08) ^c	9.45 (3.15) ^d	9.80 (3.21) ^d	10.15 (3.26) ^d	9.60	9.90 (3.22) ^c	10.15 (3.26) ^d	10.45 (3.31) ^c	11.15 (3.41) ^c	10.41	10.01	-			

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x + 0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 12. Effect of pyridine derivative 20 SC on coccolliids in tomato (Location: Mathampatti - II season)

Treatment	Doseg a.i.ha ⁻¹	Number ten plants ⁻¹												Pooled Mean
		I spray						II spray						
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean		
Pyridine derivative 20 SC	40	5.25 (2.40)	4.75 (2.29) ^b	4.00 (2.12) ^b	4.00 (2.12) ^b	4.50 (2.24) ^{ab}	4.31	3.00 (1.87) ^b	3.50 (2.00) ^b	4.25 (2.18) ^b	5.50 (2.45) ^b	4.06	4.19	
Pyridine derivative 20 SC	50	6.00 (2.55)	3.25 (1.94) ^c	3.50 (2.00) ^{bc}	3.75 (2.06) ^{bc}	3.75 (2.06) ^{bc}	3.56	2.25 (1.66) ^{bc}	2.75 (1.80) ^c	4.25 (2.18) ^b	5.00 (2.35) ^{bc}	3.56	3.56	
Pyridine derivative 20 SC	60	5.25 (2.40)	2.50 (1.73) ^{cd}	3.00 (1.87) ^{cd}	3.25 (1.94) ^{cd}	3.50 (2.00) ^c	3.06	1.75 (1.50) ^c	2.00 (1.58) ^d	3.50 (2.00) ^b	4.75 (2.29) ^{bc}	3.00	3.03	
Chlorantraniliprole 20 SC	30	5.75 (2.50)	2.00 (1.58) ^d	2.50 (1.73) ^d	3.00 (1.87) ^d	3.25 (1.94) ^c	2.69	2.75 (1.80) ^b	2.50 (1.73) ^{cd}	2.75 (1.80) ^c	3.50 (2.00) ^d	2.88	2.78	
Novaluron 10 EC	75	5.50 (2.45)	3.00 (1.87) ^c	3.50 (2.00) ^{bc}	2.75 (1.80) ^d	3.50 (2.00) ^c	3.19	3.00 (1.87) ^b	3.00 (1.87) ^{bc}	3.75 (2.06) ^b	4.50 (2.24) ^c	3.56	3.38	
Untreated check	-	5.25 (2.40)	6.00 (2.55) ^a	5.50 (2.45) ^a	5.00 (2.35) ^a	5.50 (2.45) ^a	5.50	5.25 (2.40) ^a	6.00 (2.55) ^a	6.50 (2.65) ^a	7.00 (2.74) ^a	6.19	5.84	

PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 13. Effect of pyridine derivative 20 SC on spiders in tomato (Location: Mathampatti - II season)

Treatment	Doseg a.i.ha ⁻¹	Number ten plants ⁻¹												Pooled Mean
		I spray						II spray						
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean		
Pyridine derivative 20 SC	40	8.25 (2.96)	6.75 (2.69) ^b	6.25 (2.60) ^b	5.50 (2.45) ^b	6.00 (2.55) ^b	6.13	4.75 (2.29) ^b	5.50 (2.45) ^b	6.75 (2.69) ^b	7.50 (2.83) ^b	6.13	6.13	
Pyridine derivative 20 SC	50	9.00 (3.08)	5.00 (2.35) ^c	5.50 (2.45) ^{bc}	5.00 (2.35) ^b	6.25 (2.60) ^b	5.44	4.00 (2.12) ^c	4.50 (2.24) ^c	5.50 (2.45) ^c	7.00 (2.74) ^{bc}	5.25	5.35	
Pyridine derivative 20 SC	60	9.00 (3.08)	4.75 (2.29) ^c	5.25 (2.40) ^{bc}	5.00 (2.35) ^b	5.75 (2.50) ^b	5.19	4.00 (2.12) ^c	4.50 (2.24) ^c	5.50 (2.45) ^c	6.75 (2.69) ^{cd}	5.19	5.19	
Chlorantraniliprole 20 SC	30	9.25 (3.12)	3.50 (2.00) ^d	3.25 (1.94) ^d	3.75 (2.06) ^c	4.75 (2.29) ^c	3.81	3.50 (2.00) ^d	4.00 (2.12) ^c	4.25 (2.18) ^d	6.25 (2.60) ^{de}	4.50	4.16	
Novaluron 10 EC	75	8.50 (3.00)	4.00 (2.12) ^d	4.50 (2.24) ^c	4.25 (2.18) ^c	5.75 (2.50) ^b	4.63	4.75 (2.29) ^b	4.25 (2.18) ^c	5.00 (2.35) ^c	6.00 (2.55) ^c	5.00	4.82	
Untreated check	-	8.50 (3.00)	9.00 (3.08) ^a	9.75 (3.20) ^a	10.25 (3.28) ^a	9.75 (3.20) ^a	9.69	9.25 (3.12) ^a	10.00 (3.24) ^a	9.75 (3.20) ^a	10.50 (3.32) ^a	9.88	9.79	

PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 14 .Effect of pyridine derivative 20 SC on fruit yield of tomato- season I and II

Treatment	Doseg a.i.ha ⁻¹	Season I- US 3140		Season II- Mahalakshmi	
		t ha ⁻¹	Increase over control (%)	t ha ⁻¹	Increase over control (%)
Pyridine derivative 20 SC	40	35.06 ^b	22.72	38.85 ^b	25.03
Pyridine derivative 20 SC	50	37.35 ^a	30.72	41.49 ^a	33.52
Pyridine derivative 20 SC	60	38.08 ^a	33.27	42.20 ^a	35.79
Chlorantraniliprole 20 SC	30	33.69 ^c	17.90	38.45 ^b	23.74
Novaluron 10 EC	75	32.50 ^d	13.73	36.30 ^c	16.81
Untreated check	-	28.57 ^e	-	31.08 ^d	-

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)
Mean of four replication

Table 15. Phytotoxic effect of pyridine derivative 20 SC on tomato (Location Thennamanallur and Mathampatti)

Treatment	Dose (g a.i. ha ⁻¹)	Phytotoxicity rating *																
		Leaf tip injury		Wilting		Vein clearing			Necrosis			Epinasty			Hyponasty			
		R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2
Pyridine derivative 20 SC	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyridine derivative 20 SC	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyridine derivative 20 SC	240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Untreated check	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Observed on 1, 3, 5, 7, 10, 14, 21 and 28 days after treatment.

Table 16. Effect of pyridine derivative 20 SC against yellow stem borer damage in rice after first and second spray (Location: Poluvampatti - I season)

Treatment	Doseg a.i.ha ⁻¹	Per cent dead heart									
		I spray			%ROC	II spray			%ROC		
		PTC	7 DAT	14 DAT		Mean	7 DAT	14 DAT		Mean	
Pyridine derivative 20 SC	40	10.38 (18.79)	9.00 (17.20) ^b	9.12 (17.55) ^{bc}	9.06	7.75 (16.14) ^{bc}	7.62 (16.01) ^{bc}	7.69	12.00	25.78	
Pyridine derivative 20 SC	50	10.19 (18.62)	8.33 (16.77) ^{ab}	8.53 (16.97) ^{ab}	8.43	7.25 (15.61) ^{ab}	7.14 (15.49) ^{ab}	7.20	18.16	30.52	
Pyridine derivative 20 SC	60	10.05 (18.48)	7.67 (16.05) ^a	7.94 (16.36) ^a	7.81	6.75 (15.05) ^a	6.67 (14.94) ^a	6.71	25.24	35.20	
Chlorantraniliprole 20 SC	30	10.25 (18.67)	8.67 (17.12) ^b	9.12 (17.57) ^{bc}	8.90	8.00 (16.41) ^{bc}	8.10 (16.52) ^{cd}	8.05	13.11	22.26	
Bifenthrin 10 EC	50	10.43 (18.84)	9.00 (17.46) ^b	9.17 (18.15) ^{cd}	9.09	8.50 (16.94) ^c	8.57 (17.02) ^d	8.54	9.13	17.58	
Untreated check	-	10.64 (19.03)	10.00 (18.43) ^c	10.59 (18.99) ^d	10.30	10.00 (18.43) ^d	10.71 (19.10) ^e	10.36	-	-	

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 17. Effect of pyridine derivative 20 SC against yellow stem borer damage in rice after third spray (Location: Poluvampatti - I season)

Treatment	Doseg a.i.ha ⁻¹	Per cent dead heart					
		I spray			III spray		
		7 DAT	14 DAT	Mean	7 DAT	14 DAT	Mean
Pyridine derivative 20 SC	40	6.41 (14.66) ^b	5.64 (13.73) ^b	6.03	45.00		
Pyridine derivative 20 SC	50	5.60 (13.69) ^a	4.91 (12.78) ^a	5.26	52.03		
Pyridine derivative 20 SC	60	5.20 (13.17) ^a	4.73 (12.55) ^a	4.97	54.68		
Chlorantraniliprole 20 SC	30	6.80 (15.11) ^{bc}	6.55 (14.82) ^c	6.68	39.07		
Bifenthrin 10 EC	50	7.20 (15.56) ^c	7.09 (15.44) ^c	7.15	34.78		
Untreated check	-	11.00 (19.36) ^d	10.91 (19.29) ^d	10.96	-		

ROC- Reduction over control; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 18. Effect of pyridine derivative 20 SC against leaf folder in rice after first and second spray (Location: Poluvampatti - I season)

Treatment	Doseg a.i.ha ⁻¹	Per cent leaf damage												
		I spray						II spray						
		PTC	3DAT	7DAT	10DAT	14DAT	Mean	% ROC	3DAT	7DAT	10DAT	14 DAT	Mean	% ROC
Pyridine derivative 20 SC	40	11.15 (19.48)	10.61 (19.01) ^b	10.29 (18.71) ^{bc}	9.93 (18.37) ^{bc}	10.00 (18.43) ^{bc}	10.21	19.73	9.60 (18.05) ^{bc}	9.35 (17.81) ^{bc}	9.11 (17.56) ^{bc}	8.64 (17.08) ^b	9.17	27.05
Pyridine derivative 20 SC	50	10.38 (18.79)	10.17 (18.60) ^b	9.87 (18.30) ^{ab}	9.59 (18.04) ^{ab}	9.72 (18.15) ^{ab}	9.84	22.64	9.33 (17.79) ^{ab}	9.09 (17.55) ^{ab}	8.86 (17.32) ^{ab}	8.27 (16.71) ^{ab}	8.89	29.28
Pyridine derivative 20 SC	60	10.77 (19.13)	10.11 (18.54) ^a	9.37 (17.80) ^a	9.06 (17.51) ^a	8.99 (17.45) ^a	9.38	26.26	8.63 (17.08) ^a	8.41 (16.86) ^a	8.20 (16.64) ^a	7.69 (16.09) ^a	8.23	34.53
Chlorantraniliprole 20 SC	30	11.54 (19.81)	10.82 (19.20) ^b	10.50 (18.91) ^{bc}	10.20 (18.62) ^{cd}	10.28 (18.70) ^{bc}	10.45	17.85	9.87 (18.29) ^{bc}	9.61 (18.03) ^{bc}	9.37 (17.79) ^{bc}	9.26 (17.71) ^c	9.53	24.18
Bifenthrin 10 EC	50	11.92 (20.19)	11.36 (19.69) ^c	11.03 (19.40) ^c	10.71 (19.10) ^d	10.83 (19.21) ^c	10.98	13.68	10.40 (18.81) ^c	10.13 (18.56) ^c	9.87 (18.31) ^c	9.85 (18.29) ^c	10.06	19.97
Untreated check	-	12.31 (20.52)	12.54 (20.74) ^d	12.76 (20.93) ^d	12.82 (20.98) ^d	12.78 (20.94) ^d	12.72	-	12.53 (20.73) ^d	12.50 (20.70) ^d	12.59 (20.79) ^d	12.65 (20.84) ^d	12.57	-

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 19. Effect of pyridine derivative 20 SC against leaf folder in rice after third spray (Location: Poluvampatti - I season)

Treatment	Doseg a.i.ha ⁻¹	Per cent damage						
		III spray						
		3DAT	7DAT	10 DAT	14 DAT	Mean	%ROC	
Pyridine derivative 20 SC	40	8.54 (16.97) ^{bc}	8.43 (16.87) ^{bc}	8.33 (16.77) ^{bc}	8.14 (16.56) ^{bc}	8.36	32.85	
Pyridine derivative 20 SC	50	8.17 (16.61) ^{ab}	8.07 (16.51) ^{ab}	7.98 (16.40) ^{ab}	7.79 (16.21) ^{ab}	8.00	35.74	
Pyridine derivative 20 SC	60	7.59 (15.99) ^a	7.50 (15.89) ^a	7.32 (15.70) ^a	7.09 (15.45) ^a	7.38	40.72	
Chlorantraniliprole 20 SC	30	8.54 (16.98) ^{bc}	8.43 (16.87) ^{bc}	8.33 (16.77) ^{bc}	8.14 (16.56) ^{bc}	8.36	32.85	
Bifenthrin 10 EC	50	9.33 (17.78) ^c	9.22 (17.67) ^c	9.11 (17.56) ^c	8.90 (17.34) ^c	9.14	26.59	
Untreated check	-	12.44 (20.65) ^d	12.41 (20.63) ^d	12.44 (20.65) ^d	12.53 (20.73) ^d	12.45	-	

ROC- Reduction over control; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 20. Effect of pyridine derivative 20 SC on spiders in rice after first and second spray (Location: Poluvampatti - I season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹											
		I spray						II spray					
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean	
Pyridine derivative 20 SC	40	7.25 (2.78)	4.50 (2.24) ^b	5.00 (2.35) ^b	5.50 (2.45) ^b	6.25 (2.60) ^b	5.31	5.00 (2.35) ^b	4.25 (2.18) ^b	5.00 (2.35) ^b	5.00 (2.35) ^b	4.81	
Pyridine derivative 20 SC	50	6.75 (2.69)	4.50 (2.24) ^b	5.00 (2.35) ^b	5.25 (2.40) ^{bc}	5.50 (2.45) ^c	5.06	4.25 (2.18) ^{bc}	4.25 (2.18) ^b	5.00 (2.35) ^b	5.00 (2.35) ^b	4.63	
Pyridine derivative 20 SC	60	6.75 (2.69)	4.00 (2.12) ^b	4.50 (2.24) ^{bc}	5.00 (2.35) ^{bc}	5.00 (2.35) ^{cd}	4.63	3.75 (2.06) ^{cd}	4.00 (2.12) ^b	4.25 (2.18) ^{bc}	4.75 (2.29) ^{bc}	4.19	
Chlorantraniliprole 20 SC	30	6.50 (2.65)	3.25 (1.94) ^c	4.00 (2.12) ^{cd}	4.75 (2.29) ^{cd}	5.00 (2.35) ^{cd}	4.25	3.75 (2.06) ^{cd}	3.50 (2.00) ^{bc}	4.00 (2.12) ^c	4.50 (2.24) ^c	3.94	
Bifenthrin 10 EC	50	7.00 (2.74)	3.25 (1.94) ^c	3.75 (2.06) ^{cd}	4.25 (2.18) ^d	4.75 (2.29) ^d	4.00	3.50 (2.00) ^d	3.00 (1.87) ^c	3.75 (2.06) ^c	4.00 (2.12) ^d	3.56	
Untreated check	-	7.00 (2.74)	7.75 (2.87) ^a	7.00 (2.74) ^a	7.00 (2.74) ^a	7.50 (2.83) ^a	7.31	6.75 (2.69) ^a	7.00 (2.74) ^a	6.50 (2.65) ^a	7.00 (2.74) ^a	6.63	

PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column means followed by a common letter are not significantly different by DMRT (P=0.05)

Table 21. Effect of pyridine derivative 20 SC on spiders in rice after third spray (Location: Poluvampatti - I season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹											
		III spray											
		3DAT	7 DAT	10 DAT	14 DAT	Mean	Pooled Mean						
Pyridine derivative 20 SC	40	3.75 (2.06) ^b	3.25 (1.94) ^b	3.50 (2.00) ^b	4.00 (2.12) ^b	3.63	4.58						
Pyridine derivative 20 SC	50	3.50 (2.00) ^{bc}	3.00 (1.87) ^b	3.25 (1.94) ^b	3.75 (2.06) ^b	3.38	4.36						
Pyridine derivative 20 SC	60	3.00 (1.87) ^{cd}	2.75 (1.80) ^{bc}	3.25 (1.94) ^b	3.50 (2.00) ^b	3.13	3.98						
Chlorantraniliprole 20 SC	30	3.00 (1.87) ^{cd}	2.75 (1.80) ^{bc}	3.00 (1.87) ^b	3.50 (2.00) ^b	3.06	3.75						
Bifenthrin 10 EC	50	2.50 (1.73) ^d	2.00 (1.58) ^c	1.75 (1.50) ^c	2.00 (1.58) ^c	2.06	3.21						
Untreated check	-	6.75 (2.69) ^a	6.50 (2.65) ^a	7.00 (2.74) ^a	7.25 (2.78) ^a	6.88	6.94						

DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 22. Effect of pyridine derivative 20 SC on mirids in rice after first and second spray (Location: Poluvampatti - I season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹										
		I spray					II spray					
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean
Pyridine derivative 20 SC	40	5.25 (2.40)	3.50 (2.00) ^b	4.00 (2.12) ^b	4.25 (2.18) ^b	4.75 (2.18) ^b	4.13	3.00 (1.87) ^b	3.50 (2.00) ^b	3.75 (2.06) ^b	4.00 (2.12) ^b	3.56
Pyridine derivative 20 SC	50	5.50 (2.45)	3.50 (2.00) ^b	4.00 (2.12) ^b	3.75 (2.06) ^b	4.50 (2.06) ^{bc}	3.94	2.75 (1.80) ^{bc}	3.00 (1.87) ^{bc}	3.25 (1.94) ^{bc}	3.25 (1.94) ^{bc}	3.06
Pyridine derivative 20 SC	60	5.00 (2.35)	2.75 (1.80) ^{bc}	3.50 (2.00) ^c	3.75 (2.06) ^b	4.00 (2.06) ^{cd}	3.50	2.50 (1.73) ^{bc}	2.75 (1.80) ^c	3.25 (1.94) ^{bc}	3.50 (2.00) ^{bc}	3.00
Chlorantraniliprole 20 SC	30	5.00 (2.35)	3.25 (1.94) ^{bc}	3.00 (1.87) ^d	3.50 (2.00) ^b	3.75 (2.00) ^d	3.38	3.00 (1.87) ^b	2.50 (1.73) ^{cd}	3.00 (1.87) ^d	3.75 (2.06) ^b	3.06
Bifenthrin 10 EC	50	6.00 (2.55)	2.50 (1.73) ^c	3.00 (1.87) ^d	3.25 (1.94) ^b	3.50 (1.94) ^d	3.06	2.25 (1.66) ^c	2.00 (1.58) ^d	2.50 (1.73) ^{cd}	2.75 (1.80) ^c	2.38
Untreated check	-	5.75 (2.50)	4.75 (2.29) ^a	5.00 (2.35) ^a	6.00 (2.55) ^a	6.00 (2.55) ^a	5.44	5.50 (2.45) ^a	6.25 (2.60) ^a	6.75 (2.69) ^a	6.50 (2.65) ^a	6.25

PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 23. Effect of pyridine derivative 20 SC on mirids in rice after third spray (Location: Poluvampatti - I season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹						
		III spray						
		3DAT	7 DAT	10 DAT	14 DAT	Mean	Pooled Mean	
Pyridine derivative 20 SC	40	3.50 (2.00) ^b	3.25 (1.94) ^b	4.00 (2.12) ^b	4.50 (2.24) ^b	3.81	3.83	
Pyridine derivative 20 SC	50	3.00 (1.87) ^{bc}	3.00 (1.87) ^{bc}	3.50 (2.00) ^{bc}	4.00 (2.12) ^{bc}	3.38	3.46	
Pyridine derivative 20 SC	60	3.00 (1.87) ^{bc}	2.25 (1.66) ^{cd}	3.00 (1.87) ^c	3.50 (2.00) ^{bc}	2.94	3.15	
Chlorantraniliprole 20 SC	30	3.00 (1.87) ^{bc}	2.25 (1.66) ^{cd}	3.00 (1.87) ^c	3.25 (1.94) ^c	2.88	3.11	
Bifenthrin 10 EC	50	2.50 (1.73) ^c	1.75 (1.50) ^d	2.00 (1.58) ^d	2.25 (1.66) ^d	2.13	2.52	
Untreated check	-	6.25 (2.60) ^a	6.75 (2.69) ^a	7.25 (2.78) ^a	7.50 (2.83) ^a	6.94	6.21	

DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 24. Effect of pyridine derivative 20 SC on rove beetle in rice after first and second spray (Location: Poluvampatti - I season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹											
		I spray						II spray					
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean	
Pyridine derivative 20 SC	40	8.75 (3.04)	6.25 (2.60) ^b	6.50 (2.74) ^b	7.00 (2.74) ^b	7.75 (2.87) ^b	6.88	4.25 (2.18) ^b	5.75 (2.50) ^{ab}	6.00 (2.55) ^b	6.50 (2.65) ^{ab}	5.63	
Pyridine derivative 20 SC	50	9.00 (3.08)	5.75 (2.50) ^{bc}	6.00 (2.69) ^{bc}	6.75 (2.78) ^{bc}	7.25 (2.78) ^{bc}	6.44	4.50 (2.24) ^{ab}	5.00 (2.35) ^b	5.75 (2.50) ^b	6.25 (2.60) ^b	5.38	
Pyridine derivative 20 SC	60	9.25 (3.12)	5.50 (2.45) ^{bc}	6.25 (2.65) ^{bc}	7.00 (2.74) ^{bc}	7.75 (2.74) ^{bc}	6.31	4.00 (2.12) ^{bc}	4.75 (2.29) ^{bc}	5.25 (2.40) ^c	5.25 (2.40) ^{bc}	4.81	
Chlorantraniliprole 20 SC	30	9.50 (3.16)	5.00 (2.35) ^c	6.25 (2.60) ^{bc}	6.75 (2.69) ^{bc}	7.25 (2.69) ^{bc}	5.88	3.25 (1.94) ^{bc}	4.00 (2.12) ^{cd}	4.00 (2.12) ^d	4.25 (2.18) ^c	3.88	
Bifenthrin 10 EC	50	8.50 (3.00)	5.25 (2.40) ^c	6.00 (2.55) ^c	6.50 (2.65) ^c	7.25 (2.65) ^c	5.88	3.00 (1.87) ^c	3.50 (2.00) ^d	4.00 (2.12) ^d	4.50 (2.24) ^c	3.75	
Untreated check	-	8.75 (3.04)	8.00 (3.92) ^a	8.75 (3.04) ^a	9.00 (3.08) ^a	9.50 (3.16) ^a	8.81	6.00 (2.55) ^a	6.75 (2.69) ^a	7.25 (2.78) ^a	8.00 (2.92) ^a	7.00	

PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 25. Effect of pyridine derivative 20 SC on rove beetle in rice after third spray (Location: Poluvampatti - I season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹										
		III spray					Pooled Mean					
		3DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean	
Pyridine derivative 20 SC	40	5.25 (2.40) ^b	4.75 (2.29) ^b	5.25 (2.40) ^b	5.75 (2.50) ^b	5.25	4.25 (2.18) ^{bc}	4.50 (2.24) ^{bc}	4.50 (2.24) ^{bc}	4.00	5.25	5.92
Pyridine derivative 20 SC	50	4.50 (2.24) ^{bc}	3.75 (2.06) ^{bc}	4.25 (2.18) ^{bc}	4.50 (2.24) ^{bc}	4.25	3.00 (1.87) ^d	3.50 (2.00) ^{cd}	3.75 (2.06) ^c	4.00	4.25	5.36
Pyridine derivative 20 SC	60	4.00 (2.12) ^{cd}	3.50 (2.00) ^{bc}	4.00 (2.12) ^c	4.50 (2.24) ^{bc}	4.00	3.50 (2.00) ^{cd}	3.75 (2.06) ^{bc}	3.75 (2.06) ^c	4.00	4.00	5.04
Chlorantraniliprole 20 SC	30	4.25 (2.18) ^{cd}	3.75 (2.06) ^{bc}	3.50 (2.00) ^{bc}	3.75 (2.06) ^{bc}	3.50	3.00 (1.87) ^d	3.50 (2.00) ^{cd}	3.75 (2.06) ^c	3.81	3.81	4.52
Bifenthrin 10 EC	50	3.50 (2.00) ^d	3.00 (1.87) ^c	3.00 (1.87) ^d	3.50 (2.00) ^c	3.00	3.00 (1.87) ^d	3.00 (1.87) ^d	3.50 (2.00) ^c	3.25	3.25	4.29
Untreated check	-	7.75 (2.87) ^a	7.00 (2.74) ^a	7.50 (2.83) ^a	8.00 (2.92) ^a	7.50	7.50 (2.83) ^a	7.50 (2.83) ^a	8.00 (2.92) ^a	7.56	7.56	7.79

DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 26. Effect of pyridine derivative 20 SC against yellow stem borer damage in rice after first and second spray (Location: Thennamanallur- II season)

Treatment	Doseg a.i.ha ⁻¹	Per cent dead heart									
		I spray					II spray				
		PTC	7 DAT	14 DAT	Mean	% ROC	7 DAT	14 DAT	Mean	% ROC	
Pyridine derivative 20 SC	40	10.81 (19.19)	9.64 (18.08) ^b	9.69 (18.13) ^{bc}	9.67	17.07	8.16 (16.59) ^{bc}	8.10 (16.52) ^b	8.13	23.45	
Pyridine derivative 20 SC	50	10.78 (19.17)	8.93 (17.38) ^{ab}	8.75 (17.18) ^b	8.84	24.15	7.37 (15.72) ^{ab}	7.15 (15.48) ^{ab}	7.26	31.64	
Pyridine derivative 20 SC	60	10.72 (19.11)	8.21 (16.64) ^a	7.50 (15.87) ^a	7.86	32.60	6.32 (14.55) ^a	5.95 (14.06) ^a	6.14	42.23	
Chlorantraniliprole 20 SC	30	11.09 (19.45)	9.29 (17.73) ^b	9.38 (17.83) ^{bc}	9.34	19.91	7.89 (16.31) ^{bc}	8.33 (16.77) ^{bc}	8.11	23.63	
Bifenthrin 10 EC	50	10.90 (19.28)	9.64 (18.09) ^b	10.00 (18.43) ^c	9.32	15.74	8.68 (17.12) ^c	8.81 (17.25) ^{cd}	8.75	17.66	
Untreated check	-	11.12 (19.47)	11.43 (19.76) ^e	11.88 (20.16) ^d	11.66	-	10.53 (18.93) ^d	10.71 (19.10) ^d	10.62	-	

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 27. Effect of pyridine derivative 20 SC against yellow stem borer damage in rice after third spray (Location: Thennamanallur - II season)

Treatment	Doseg a.i.ha ⁻¹	Per cent dead heart					
		III spray			%ROC		
		7 DAT	14 DAT	Mean	7 DAT	14 DAT	Mean
Pyridine derivative 20 SC	40	7.08 (15.43) ^{bc}	6.54 (14.81) ^b	6.81	33.17		
Pyridine derivative 20 SC	50	5.83 (13.96) ^{ab}	4.81 (12.66) ^a	5.32	47.79		
Pyridine derivative 20 SC	60	5.00 (12.90) ^a	4.62 (12.39) ^a	4.81	52.80		
Chlorantraniliprole 20 SC	30	7.29 (15.66) ^{bc}	6.92 (15.26) ^b	7.11	30.27		
Bifenthrin 10 EC	50	7.71 (16.10) ^c	7.69 (16.10) ^c	7.70	24.44		
Untreated check	-	10.00 (18.43) ^d	10.38 (18.80) ^d	10.19	-		

ROC- Reduction over control; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 28. Effect of pyridine derivative 20 SC against leaf folder in rice after first and second spray (Location: Thennamanallur - II season)

Treatment	Doseg a.i.ha ⁻¹	Per cent leaf damage												
		I spray						II spray						
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	%ROC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	%ROC
Pyridine derivative 20 SC	40	10.26 (18.68)	10.11 (18.54) ^{cd}	9.82 (18.26) ^f	9.26 (17.72) ^{bc}	9.33 (17.79) ^b	9.63	12.22	9.20 (17.66) ^{ab}	8.95 (17.41) ^b	8.80 (17.26) ^b	8.68 (17.14) ^b	8.91	19.87
Pyridine derivative 20 SC	50	10.38 (18.69)	9.92 (18.36) ^{ab}	9.63 (18.08) ^{ab}	9.08 (17.54) ^{ab}	9.15 (17.61) ^{ab}	9.44	13.95	9.03 (17.48) ^{ab}	8.72 (17.17) ^{ab}	8.57 (17.02) ^{ab}	8.45 (16.90) ^{ab}	8.69	21.85
Pyridine derivative 20 SC	60	10.50 (18.91)	9.85 (18.29) ^a	9.56 (18.01) ^a	8.94 (17.40) ^a	8.98 (17.44) ^a	9.33	14.95	8.85 (17.31) ^a	8.28 (16.72) ^a	8.13 (16.57) ^a	8.03 (16.46) ^a	8.32	25.18
Chlorantraniliprole 20 SC	30	10.39 (18.80)	10.23 (18.65) ^d	9.74 (18.19) ^{bc}	9.33 (17.79) ^c	9.86 (18.30) ^c	9.79	10.76	9.27 (17.73) ^b	9.05 (17.51) ^b	8.93 (17.39) ^b	8.82 (17.27) ^b	9.02	18.88
Bifenthrin 10 EC	50	10.15 (18.57)	10.00 (18.43) ^{bc}	9.78 (18.22) ^f	9.37 (17.82) ^c	9.54 (17.99) ^d	9.67	11.85	9.41 (17.86) ^b	9.19 (17.65) ^b	9.07 (17.52) ^b	8.95 (17.40) ^b	9.15	17.72
Untreated check	-	10.75 (19.14)	10.95 (19.32) ^e	10.85 (19.23) ^d	10.99 (19.36) ^d	11.09 (19.45) ^e	10.97	-	11.04 (19.41) ^f	11.18 (19.53) ^f	11.13 (19.49) ^f	11.12 (19.48) ^f	11.12	-

ROC- Reduction over control; PTC- Pretreatment count; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 29. Effect of pyridine derivative 20 SC against leaf folder in rice after third spray (Location: Thennamanallur - II season)

Treatment	Doseg a.i.ha ⁻¹	Per cent damage					
		III spray					
		3DAT	7 DAT	10 DAT	14 DAT	Mean	%ROC
Pyridine derivative 20 SC	40	8.57 (17.02) ^{bc}	8.43 (16.83) ^b	8.22 (16.66) ^{bc}	8.16 (16.60) ^b	8.34	24.46
Pyridine derivative 20 SC	50	8.31 (16.75) ^{yb}	8.17 (16.59) ^{yb}	7.94 (16.36) ^{ab}	7.85 (16.27) ^{ab}	8.07	26.90
Pyridine derivative 20 SC	60	7.89 (16.31) ^a	7.69 (16.10) ^a	7.44 (15.83) ^a	7.35 (15.72) ^a	7.59	31.25
Chlorantraniliprole 20 SC	30	8.70 (17.15) ^{bc}	8.59 (17.04) ^b	8.38 (16.82) ^{bc}	8.35 (16.79) ^b	8.50	23.01
Bifenthrin 10 EC	50	8.83 (17.29) ^c	8.72 (17.16) ^b	8.50 (16.95) ^c	8.47 (16.92) ^b	8.63	21.83
Untreated check	-	11.04 (19.40) ^d	11.03 (19.39) ^c	11.00 (19.37) ^d	11.09 (19.85) ^e	11.04	-

ROC- Reduction over control; DAT - Days after Treatment

Values in parentheses are arc sine transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 30. Effect of pyridine derivative 20 SC on spiders in rice after first and second spray (Location: Thenamanallur - II season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹										
		I spray					II spray					
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean
Pyridine derivative 20 SC	40	8.25 (2.96)	4.50 (2.24) ^b	5.00 (2.35) ^b	5.75 (2.50) ^b	6.50 (2.65) ^b	5.44	4.75 (2.29) ^c	5.00 (2.35) ^b	6.75 (2.69) ^b	7.25 (2.78) ^b	5.94
Pyridine derivative 20 SC	50	7.75 (2.87)	4.00 (2.12) ^{bc}	4.75 (2.29) ^b	5.50 (2.45) ^b	6.50 (2.65) ^b	5.19	5.75 (2.50) ^b	5.25 (2.40) ^b	6.00 (2.55) ^{bc}	6.75 (2.69) ^b	5.94
Pyridine derivative 20 SC	60	8.50 (3.00)	3.75 (2.06) ^{bc}	4.25 (2.18) ^b	5.25 (2.40) ^b	5.75 (2.50) ^{bc}	4.75	4.00 (2.12) ^d	4.00 (2.12) ^{bc}	5.50 (2.45) ^{cd}	6.50 (2.65) ^c	5.00
Chlorantraniliprole 20 SC	30	8.00 (2.92)	3.50 (2.00) ^c	4.25 (2.18) ^b	5.00 (2.35) ^b	5.50 (2.45) ^{cd}	4.56	4.25 (2.18) ^{cd}	4.50 (2.24) ^{bc}	5.00 (2.35) ^{de}	6.25 (2.60) ^d	5.00
Bifenthrin 10 EC	50	8.00 (2.92)	2.75 (1.80) ^d	3.50 (2.00) ^c	4.25 (2.18) ^c	4.75 (2.29) ^d	3.81	3.75 (2.06) ^d	3.50 (2.00) ^e	4.75 (2.29) ^e	6.00 (2.55) ^{bc}	4.50
Untreated check	-	8.50 (3.00)	7.50 (2.83) ^a	7.25 (2.78) ^a	8.00 (2.92) ^a	8.50 (3.00) ^a	7.81	8.00 (2.92) ^a	7.50 (2.83) ^a	8.25 (2.96) ^a	8.75 (3.04) ^a	8.13

PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 31. Effect of pyridine derivative 20 SC on spiders in rice after third spray (Location: Thenamanallur - II season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹						
		III spray						
		3DAT	7 DAT	10 DAT	14 DAT	Mean	Pooled Mean	
Pyridine derivative 20 SC	40	5.00 (2.35) ^b	4.25 (2.18) ^b	4.75 (2.29) ^b	5.00 (2.35) ^b	4.75	5.38	
Pyridine derivative 20 SC	50	4.50 (2.24) ^{bc}	4.00 (2.12) ^b	4.25 (2.18) ^{bc}	4.75 (2.29) ^{bc}	4.38	5.17	
Pyridine derivative 20 SC	60	4.25 (2.18) ^{bc}	3.75 (2.06) ^{bc}	4.00 (2.12) ^{bc}	4.50 (2.24) ^{bc}	4.13	4.65	
Chlorantraniliprole 20 SC	30	4.00 (2.12) ^c	3.25 (1.94) ^c	3.75 (2.06) ^{bc}	4.25 (2.18) ^{cd}	3.81	4.46	
Bifenthrin 10 EC	50	3.75 (2.06) ^c	3.25 (1.94) ^c	3.50 (2.00) ^c	3.75 (2.06) ^d	3.56	3.96	
Untreated check	-	8.00 (2.92) ^a	8.50 (3.00) ^a	8.00 (2.92) ^a	8.50 (3.00) ^a	8.25	8.06	

DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 32. Effect of pyridine derivative 20 SC on mirids in rice after first and second spray (Location: Themamanallur - II season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹										
		I spray					II spray					
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean
Pyridine derivative 20 SC	40	6.50 (2.65)	3.75 (2.06) ^b	4.50 (2.24) ^b	4.50 (2.24) ^b	5.00 (2.35) ^b	4.44	2.75 (1.80) ^b	3.50 (2.00) ^b	4.25 (2.18) ^b	5.00 (2.35) ^b	3.88
Pyridine derivative 20 SC	50	6.00 (2.55)	4.00 (2.12) ^b	4.00 (2.12) ^b	4.25 (2.18) ^b	4.75 (2.29) ^b	4.25	3.00 (1.87) ^b	3.50 (2.00) ^b	4.00 (2.12) ^b	4.00 (2.12) ^c	3.63
Pyridine derivative 20 SC	60	6.50 (2.65)	3.50 (2.00) ^b	3.75 (2.06) ^{cd}	4.00 (2.12) ^b	4.50 (2.24) ^b	3.94	2.50 (1.73) ^b	3.75 (2.06) ^b	3.50 (2.00) ^{cd}	4.00 (2.12) ^c	3.44
Chlorantraniliprole 20 SC	30	6.25 (2.60)	3.00 (1.87) ^{cd}	3.25 (1.94) ^d	3.25 (1.94) ^e	3.75 (2.06) ^c	3.31	2.25 (1.66) ^b	2.50 (1.73) ^c	3.50 (2.00) ^{cd}	4.25 (2.18) ^c	3.13
Bifenthrin 10 EC	50	6.25 (2.60)	2.50 (1.73) ^d	3.00 (1.87) ^e	3.25 (1.94) ^e	3.25 (1.94) ^c	3.00	1.75 (1.50) ^c	2.25 (1.66) ^c	3.00 (1.87) ^d	3.75 (2.06) ^c	2.69
Untreated check	-	6.50 (2.65)	5.50 (2.45) ^a	6.00 (2.55) ^a	6.50 (2.65) ^a	7.25 (2.78) ^a	6.31	7.50 (2.83) ^a	7.50 (2.83) ^a	8.00 (2.92) ^a	7.75 (2.87) ^a	7.69

PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 33. Effect of pyridine derivative 20 SC on mirids in rice after third spray (Location: Themamanallur - II season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹						
		III spray						
		3DAT	7 DAT	10 DAT	14 DAT	Mean	Pooled Mean	
Pyridine derivative 20 SC	40	3.25 (1.94) ^b	3.00 (1.87) ^b	3.75 (2.06) ^b	4.00 (2.12) ^b	3.50	3.94	
Pyridine derivative 20 SC	50	3.25 (1.94) ^b	2.75 (1.80) ^b	3.00 (1.87) ^{bc}	3.25 (1.94) ^c	3.06	3.65	
Pyridine derivative 20 SC	60	3.00 (1.87) ^{bc}	2.50 (1.73) ^{bc}	3.00 (1.87) ^{bc}	3.00 (1.87) ^c	2.88	3.42	
Chlorantraniliprole 20 SC	30	2.25 (1.66) ^{cd}	2.25 (1.66) ^c	3.00 (1.87) ^{bc}	3.50 (2.00) ^{bc}	2.75	3.06	
Bifenthrin 10 EC	50	2.00 (1.58) ^d	1.50 (1.41) ^d	2.50 (1.73) ^c	3.00 (1.87) ^c	2.25	2.65	
Untreated check	-	7.00 (2.74) ^a	7.75 (2.87) ^a	8.25 (2.96) ^a	8.00 (2.92) ^a	7.75	7.25	

DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 34. Effect of pyridine derivative 20 SC on rove beetle in rice after first and second spray (Location: Thennamanallur - II season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹										
		I spray					II spray					
		PTC	3 DAT	7 DAT	10 DAT	14 DAT	Mean	3 DAT	7 DAT	10 DAT	14 DAT	Mean
Pyridine derivative 20 SC	40	7.75 (2.87)	5.50 (2.45) ^b	6.25 (2.60) ^b	6.75 (2.69) ^b	7.50 (2.83) ^b	6.50	5.50 (2.45) ^b	5.50 (2.45) ^b	6.00 (2.55) ^b	6.75 (2.69) ^b	5.94
Pyridine derivative 20 SC	50	7.75 (2.87)	5.00 (2.35) ^{bc}	5.75 (2.50) ^b	6.50 (2.65) ^{bc}	7.00 (2.74) ^{bc}	6.06	5.00 (2.35) ^b	5.50 (2.45) ^b	5.75 (2.50) ^{bc}	6.25 (2.60) ^{bc}	5.63
Pyridine derivative 20 SC	60	7.50 (2.83)	4.50 (2.24) ^{cd}	5.25 (2.40) ^{bc}	6.00 (2.55) ^c	6.50 (2.65) ^{cd}	5.56	4.00 (2.12) ^{cd}	4.75 (2.29) ^c	5.50 (2.45) ^{bc}	6.00 (2.55) ^c	5.06
Chlorantraniliprole 20 SC	30	8.25 (2.96)	4.50 (2.24) ^{cd}	5.25 (2.40) ^{bc}	6.00 (2.55) ^c	6.25 (2.60) ^{bc}	5.50	4.25 (2.18) ^c	4.75 (2.29) ^c	5.25 (2.40) ^{cd}	5.75 (2.50) ^{cd}	5.00
Bifenthrin 10 EC	50	8.00 (2.92)	3.75 (2.06) ^d	4.50 (2.24) ^c	5.25 (2.40) ^d	5.75 (2.50) ^c	4.81	3.50 (2.00) ^d	4.25 (2.18) ^c	4.75 (2.29) ^d	5.25 (2.40) ^d	4.44
Untreated check	-	7.25 (2.78)	8.00 (2.92) ^a	8.50 (3.00) ^a	8.50 (3.00) ^a	9.25 (3.12) ^a	8.56	7.75 (2.87) ^a	8.25 (2.96) ^a	8.75 (3.04) ^a	9.50 (3.16) ^a	8.56

PTC- Pretreatment count; DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05)

Table 35. Effect of pyridine derivative 20 SC on rove beetle in rice after third spray (Location: Thennamanallur - II season)

Treatment	Doseg a.i.ha ⁻¹	Numbers ten hills ⁻¹						
		III spray						
		3DAT	7 DAT	10 DAT	14 DAT	Mean	Pooled Mean	
Pyridine derivative 20 SC	40	5.50 (2.45) ^b	4.75 (2.29) ^b	5.25 (2.40) ^b	5.75 (2.50) ^b	5.31	5.92	
Pyridine derivative 20 SC	50	5.00 (2.35) ^{bc}	4.25 (2.18) ^{bc}	4.75 (2.29) ^{bc}	5.25 (2.40) ^{bc}	4.81	5.50	
Pyridine derivative 20 SC	60	5.00 (2.35) ^{bc}	4.25 (2.18) ^{bc}	4.50 (2.24) ^{bc}	5.00 (2.35) ^{bcd}	4.69	5.10	
Chlorantraniliprole 20 SC	30	4.50 (2.24) ^c	4.00 (2.12) ^{bc}	4.25 (2.18) ^c	4.75 (2.29) ^{cd}	4.38	4.96	
Bifenthrin 10 EC	50	4.25 (2.18) ^c	3.75 (2.06) ^c	4.00 (2.12) ^c	4.50 (2.24) ^d	4.13	4.46	
Untreated check	-	9.25 (3.12) ^a	8.50 (3.00) ^a	9.00 (3.08) ^a	9.75 (3.20) ^a	9.13	8.75	

DAT - Days after Treatment

Figures in parentheses are $\sqrt{x+0.5}$ transformed values

In a column means followed by a common letter are not significantly different by DMRT (P=0.05)

Table 36. Effect of pyridine derivative 20 SC on yield of rice- season I and II

Treatment	Doseg a.i.ha ⁻¹	Season I		Season II	
		t ha ⁻¹	Increase over control (%)	t ha ⁻¹	Increase over control (%)
Pyridine derivative 20 SC	40	4.27 ^{bc}	34.25	3.62 ^{bc}	33.46
Pyridine derivative 20 SC	50	4.69 ^{ab}	47.29	3.98 ^{ab}	46.82
Pyridine derivative 20 SC	60	4.92 ^a	54.44	4.30 ^a	58.34
Chlorantraniliprole 20 SC	30	3.92 ^c	23.02	3.46 ^c	27.56
Bifenthrin 10 EC	50	3.83 ^c	20.35	3.31 ^c	21.84
Untreated check	-	3.18 ^d	-	2.71 ^d	-

In a column, means followed by common superscripts are not significantly different by DMRT (P=0.05) (Mean of four replication)

Table 37. Phytotoxic effect of pyridine derivative 20 SC on rice (Location Poluvampatti and Thennamanallur)

Treatment	Dose (g a.i. ha ⁻¹)	Phytotoxicity rating *																
		Leaf tip injury		Wilting		Vein clearing			Necrosis			Epinasty			Hyponasty			
		R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2
Pyridine derivative 20 SC	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyridine derivative 20 SC	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyridine derivative 20 SC	240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Untreated check	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Observed on 1, 3, 5, 7, 10, 14, 21 and 28 days after treatment



Argiope sp.



Plexippus paykulli
(Audouin)



Pardosa birmanica
Simon



Tetragnatha sp.



Peucetia viridana
(Hentz)



Pardosa sp.



Unidentified spider sp. 1



Harmochirus brachiatus
(Thorell)



Pardosa birmanica
Simon



Neoscona theisi
(Walckenaer)



Unidentified spider sp. 2

Plate 9a. Photo inventory of arthropods in tomato ecosystem
(Order: Araneae)

Plate 9b. Photo inventory of arthropods in tomato ecosystem
(Order: Araneae)



Atractomorpha similis
Bolivar



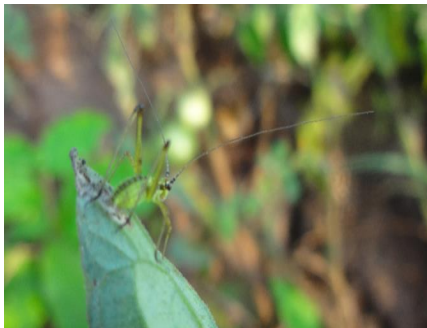
Trilophidia annulata
Thunberg



Unidentified grasshopper sp.



Gryllus sp.



Phaneroptera gracilis Burmeister



Tridactylus sp.

**Plate 10. Photo inventory of arthropods in tomato ecosystem
(Order: Orthoptera)**



Pantala flavescens
(Fabricius)



Amrasca biguttula biguttula
(Ishida)



Aphis gossypii Glover



Nezara viridula
(Linnaeus)



Macrolophus sp.



Cletus bipunctatus Westd

**Plate 11. Photo inventory of arthropods in tomato ecosystem
(Order: Odonata and Hemiptera)**



Nisia atrovonosa
(Motschulsky)



Oxycarenus hyalinipennis
(Costa)



Tipula sp.



Solenopsis geminata
(Fabricius)



Lygaeus hospes (Fabricius)



Peregrinus maidis (Ashmead)



Delta camponiforme
(Fabricius)



Spodoptera litura
(Fabricius)



Liriomyza trifolii
(Burgess)



Sepsis sp.



Helicoverpa armigera
Hubner

**Plate 12. Photo inventory of arthropods in tomato ecosystem
(Order: Hemiptera and Diptera)**

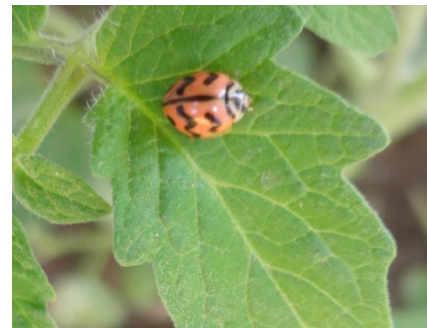
**Plate 13a. Photo inventory of arthropods in tomato ecosystem
(Order: Hemiptera, Hymenoptera and Lepidoptera)**



Trichoplusia ni
(Hubner)



Danaus chrysippus
(Linnaeus)



Cheilomenes sexmaculata
(Fabricius)



Chilocorus nigrinus
(Fabricius)



Ergolis merione
(Cramer)



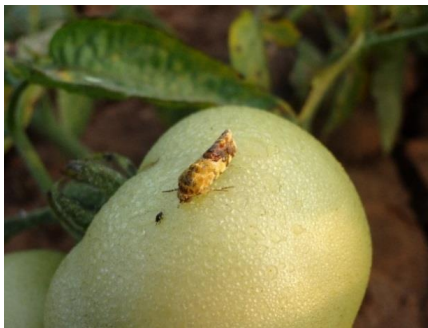
Lampides boeticus
(Linnaeus)



Micraspis discolor
(Fabricius)



Aulacophora foveicollis
(Lucas)



Unidentified moth sp.



Myllocerus sp.



Epitrix cucumeris
(Harris)

Plate 13b . Photo inventory of arthropods in tomato ecosystem
(Order: Lepidoptera)

Plate 14a. . Photo inventory of arthropods in tomato ecosystem
(Order: Coleoptera)



Oxycetonia versicolor (Fabricius)



Alphitobius sp.



Paederus sp.

Plate 14b. Photo inventory of arthropods in tomato ecosystem (Order: Coleoptera)

Table 39. Arthropod diversity in tomato ecosystem - Alpha diversity (Species number)

Month	Sampling week	Species richness indices (Species number)									
		Sprayed field			Unsprayed field			Species level			
		Ordinal level	Familial level	Generic level	Ordinal level	Familial level	Generic level	Ordinal level	Familial level	Generic level	
November	1 st week	11	34	41	43	37	49	10	37	49	51
	2 nd week	11	37	48	50	43	53	12	43	53	55
	3 rd week	11	35	43	43	44	56	12	44	56	58
	4 th week	11	34	42	43	43	54	11	43	54	56
December	1 st week	8	36	41	42	42	52	12	42	52	53
	2 nd week	11	35	42	42	43	51	12	43	51	51
	3 rd week	14	32	35	35	41	50	14	41	50	51
	4 th week	10	31	35	36	36	43	10	36	43	44
January	1 st week	12	36	42	43	38	45	11	38	45	47
	2 nd week	10	32	38	39	38	44	10	38	44	46

Table 40. Arthropod diversity in tomato ecosystem - Alpha diversity (Fishers alpha)

Month	Sampling week	Species richness indices (Fishers alpha)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
November	1 st week	3.1399	18.001	25.7	28.306	2.5213	17.169	28.41	30.691		
	2 nd week	3.1164	20.694	34.973	38.303	2.9283	18.271	25.956	27.701		
	3 rd week	3.1896	19.651	29.576	29.576	2.8057	17.438	25.83	27.419		
	4 th week	3.128	17.858	26.707	28.014	2.5567	17.483	25.451	27.083		
December	1 st week	1.768	14.35	17.684	18.399	2.7139	15.257	21.26	21.926		
	2 nd week	3.0826	18.243	25.706	25.706	2.7811	16.544	21.694	21.694		
	3 rd week	4.8524	19.301	23.102	23.102	3.585	16.864	23.389	24.195		
	4 th week	2.9421	17.57	22.256	23.568	2.4403	15.34	20.657	21.488		
January	1 st week	3.603	20.726	28.152	29.576	2.7615	16.689	22.234	24.01		
	2 nd week	2.6875	15.363	20.876	21.913	2.5341	18.167	23.549	25.564		

Table 41. Arthropod diversity in tomato ecosystem - Alpha diversity (Q Statistic)

Month	Sampling week	Species richness indices (Q Statistic)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
November	1 st week	2.6525	11.542	13.706	16.839	3.1708	16.23	24.121	25.942		
	2 nd week	3.2055	17.295	23.211	28.133	2.977	18.553	26.397	28.673		
	3 rd week	3.0373	15.019	17.295	17.295	2.3392	15.533	20.193	23.804		
	4 th week	2.5247	9.9414	15.019	15.929	2.0788	12.837	18.755	19.837		
December	1 st week	3.1604	10.883	14.788	14.788	3.13	12.837	15.627	16.465		
	2 nd week	2.8037	15.474	23.083	23.083	2.4723	14.912	18.034	18.034		
	3 rd week	3.8472	18.034	20.198	20.198	2.579	20.025	23.211	24.121		
	4 th week	2.164	13.654	14.109	14.109	1.864	16.839	19.57	19.57		
January	1 st week	2.9192	15.474	18.205	19.115	2.3053	14.788	19.57	21.391		
	2 nd week	3.1067	10.252	12.984	12.984	4.5512	14.427	16.591	19.57		

Table 42. Arthropod diversity in tomato ecosystem - Alpha diversity (Margalef's D)

Month	Sampling week	Species richness indices (Margalef's D)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
November	1 st week	2.1668	7.1504	8.6672	9.1005	1.8461	7.3843	9.8458	10.256		
	2 nd week	2.1576	7.7674	10.141	10.572	2.1322	8.141	10.079	10.467		
	3 rd week	2.1859	7.4322	9.1809	9.1809	2.0761	8.1158	10.381	10.758		
	4 th week	2.1622	7.1352	8.8649	9.0811	1.9116	8.0289	10.132	10.514		
December	1 st week	1.3759	6.8795	7.8623	8.0588	2.0327	7.5763	9.4241	9.6089		
	2 nd week	2.1443	7.2908	8.7918	8.7918	2.0646	7.8831	9.3846	9.3846		
	3 rd week	2.95	7.0347	7.7155	7.7155	2.517	7.7448	9.4873	9.6809		
	4 th week	2.0258	6.7527	7.6531	7.8782	1.8084	7.0327	8.4393	8.6402		
January	1 st week	2.4045	7.6508	8.9623	9.1809	2.0066	7.4243	8.8289	9.2303		
	2 nd week	1.9222	6.6209	7.9024	8.116	1.8519	7.6135	8.8481	9.2596		

Table 43. Arthropod diversity in tomato ecosystem - Alpha diversity (Shannon - Weiner index)

Month	Sampling week	Species richness (Shannon - Weiner index)																			
		Sprayed field										Unsprayed field									
		Ordinal level	Familial level		Generic level		Species level		Ordinal level	Familial level		Generic level		Species level							
November	1 st week	2.0252	0.0655138	3.214	0.0071089	3.4087	0.0075236	3.4622	0.0077021	1.9846	0.003913	3.2037	0.0072266	3.4664	0.0085686	3.5127	0.0087686				
	2 nd week	1.9918	0.0063533	3.3006	0.0079066	3.5415	0.0092441	3.5943	0.0094629	2.0773	0.0033089	3.3688	0.0063147	3.5703	0.0060096	3.6006	0.0062265				
	3 rd week	2.0164	0.006204	3.1503	0.010062	3.3752	0.010281	3.3752	0.010281	1.9381	0.0033419	3.2989	0.0060255	3.5206	0.005779	3.5522	0.0059839				
	4 th week	1.9081	0.0078344	3.1412	0.0081524	3.3446	0.0091035	3.3833	0.0093624	1.9426	0.0028988	3.2218	0.0066511	3.4475	0.0060977	3.4687	0.0063555				
December	1 st week	1.8366	0.028321	2.982	0.0073618	3.1239	0.0075986	3.1325	0.007779	1.9423	0.0034454	3.1214	0.0048325	3.3331	0.0053916	3.3393	0.0054071				
	2 nd week	1.917	0.0072036	3.1303	0.0094891	3.2652	0.011388	3.2652	0.011388	1.9296	0.003386	3.1249	0.0059707	3.3362	0.0057686	3.3362	0.0057686				
	3 rd week	2.0214	0.013003	3.0755	0.011744	3.1789	0.011979	3.1799	0.011979	2.0034	0.0043639	3.0959	0.0072251	3.3076	0.0074126	3.3185	0.007573				
	4 th week	1.8995	0.0068552	3.0268	0.01166	3.1982	0.010559	3.2125	0.01087	1.8881	0.0036154	2.9487	0.0088803	3.1565	0.0090631	3.166	0.0092806				
January	1 st week	2.0184	0.0071084	3.1512	0.011496	3.3933	0.0093885	3.413	0.0096346	1.9704	0.0039587	3.0772	0.0088074	3.291	0.0086474	3.3195	0.0090337				
	2 nd week	2.0089	0.0042446	3.0661	0.0076426	3.2501	0.0080965	3.263	0.0083959	1.9112	0.0047249	3.129	0.0089515	3.3443	0.0079015	3.3724	0.0082155				

Table 44. Arthropod diversity in tomato ecosystem - Alpha diversity (Brillouin diversity index)

Month	Sampling week	Species richness indices (Brillouin diversity index)											
		Sprayed field						Unsprayed field					
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level
November	1 st week	1.8613	2.7916	2.9222	2.9587	1.8566	2.8324	3.0109	3.0422				
	2 nd week	1.8303	2.8527	3.0044	3.0306	1.9601	3.0243	3.1678	3.1874				
	3 rd week	1.8464	2.7157	2.8694	2.8694	1.8393	2.9919	3.1536	3.1752				
	4 th week	1.7496	2.7316	2.8674	2.8781	1.8439	2.9126	3.0809	3.0942				
December	1 st week	1.7443	2.6698	2.7968	2.8011	1.8488	2.8611	3.0258	3.0289				
	2 nd week	1.7622	2.7223	2.8034	2.8034	1.832	2.8422	3.0119	3.0119				
	3 rd week	1.8008	2.6188	2.6895	2.6895	1.8818	2.7866	2.9485	2.9548				
	4 th week	1.7312	2.5927	2.7174	2.7256	1.7579	2.6328	2.7912	2.796				
January	1 st week	1.8421	2.708	2.8894	2.9008	1.8481	2.7382	2.902	2.9191				
	2 nd week	1.86	2.691	2.8216	2.828	1.7854	2.7578	2.9253	2.9414				

Table 45. Arthropod diversity in tomato ecosystem - Alpha diversity (Simpson's index)

Month	Sampling week	Species dominance indices (Simpson's index)											
		Sprayed field						Unsprayed field					
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level
November	1 st week	6.6013	24.396	31.173	33.007	6.2063	19.895	24.329	25.118				
	2 nd week	6.0799	25.134	31.836	33.038	6.7222	22.77	26.313	26.686				
	3 rd week	6.4937	19.897	26.606	26.606	5.6938	20.494	24.15	24.507				
	4 th week	5.2723	21.552	26.828	27.111	6.0073	19.069	23.758	23.922				
December	1 st week	5.3711	13.873	15.846	15.865	5.4688	17.154	20.455	20.472				
	2 nd week	5.4828	18.612	19.875	19.875	5.6944	16.045	20.885	20.885				
	3 rd week	5.6769	19.197	21.565	21.565	6.1022	15.599	19.494	19.544				
	4 th week	5.8717	17.33	23.032	23.182	5.622	13.471	16.493	16.519				
January	1 st week	6.3607	17.703	28.048	28.39	6.1684	14.48	18.156	18.313				
	2 nd week	6.7579	19.455	23.68	23.778	5.5784	16.645	23.793	24.07				

Table 46. Arthropod diversity in tomato ecosystem - Alpha diversity (Berger Parker diversity index)

Month	Sampling week	Species dominance indices (Berger Parker diversity index)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
November	1 st week	0.27723	0.10891	0.07921	0.07921	0.30534	0.1374	0.1374	0.1374	0.1374	
	2 nd week	0.31068	0.1068	0.1068	0.1068	0.27011	0.11494	0.11494	0.11494	0.11494	
	3 rd week	0.26804	0.13402	0.10309	0.10309	0.305	0.14	0.14	0.14	0.14	
	4 th week	0.35294	0.10784	0.07843	0.07843	0.26738	0.12834	0.12834	0.12834	0.12834	
December	1 st week	0.30247	0.18519	0.18519	0.18519	0.32143	0.13393	0.13393	0.13393	0.13393	
	2 nd week	0.31132	0.14151	0.14151	0.14151	0.2767	0.15534	0.10194	0.10194	0.10194	
	3 rd week	0.29268	0.13415	0.12195	0.12195	0.26857	0.14286	0.12571	0.12571	0.12571	
	4 th week	0.28235	0.16471	0.10588	0.10588	0.29655	0.16552	0.16552	0.16552	0.16552	
January	1 st week	0.25773	0.18557	0.10309	0.10309	0.23288	0.17808	0.17808	0.17808	0.17808	
	2 nd week	0.22222	0.10185	0.09259	0.09259	0.31783	0.17829	0.10853	0.10853	0.10853	

Table 47. Arthropod diversity in tomato ecosystem - (McIntosh, 1967)

Month	Sampling week	Species dominance indices (McIntosh, 1967)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
November	1 st week	0.66646	0.86098	0.88383	0.88868	0.64724	0.83295	0.85461	0.85783		
	2 nd week	0.64846	0.86347	0.8852	0.88832	0.65789	0.84151	0.85627	0.85764		
	3 rd week	0.66404	0.84027	0.87041	0.87041	0.61986	0.82707	0.84479	0.8463		
	4 th week	0.6165	0.84784	0.87001	0.871	0.63285	0.82017	0.84447	0.84518		
December	1 st week	0.61071	0.78254	0.80041	0.80057	0.60882	0.8037	0.82459	0.82468		
	2 nd week	0.62466	0.83034	0.83792	0.83792	0.61935	0.79692	0.8286	0.8286		
	3 rd week	0.63907	0.84053	0.85341	0.85341	0.63752	0.79668	0.82414	0.82444		
	4 th week	0.64569	0.82748	0.8594	0.86006	0.62335	0.78092	0.80805	0.80825		
January	1 st week	0.65966	0.82661	0.87535	0.87646	0.64356	0.79079	0.81975	0.82078		
	2 nd week	0.66964	0.83502	0.85636	0.85678	0.62411	0.81194	0.85269	0.85388		

Table 48. Arthropod diversity in tomato ecosystem - Alpha diversity (Equitability J)

Month	Sampling week	Evenness indices (Equitability J)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
November	1 st week	0.76738	0.83022	0.82224	0.8294	0.75201	0.82757	0.83666	0.84149		
	2 nd week	0.75475	0.85261	0.85478	0.85864	0.78713	0.87022	0.86174	0.86255		
	3 rd week	0.76404	0.81377	0.81464	0.80854	0.73438	0.85215	0.84974	0.85095		
	4 th week	0.72301	0.81142	0.80725	0.80569	0.73611	0.83225	0.8321	0.83119		
December	1 st week	0.69594	0.76513	0.754	0.75041	0.73598	0.80632	0.80449	0.79995		
	2 nd week	0.72639	0.80861	0.7881	0.7822	0.73118	0.80721	0.80522	0.7992		
	3 rd week	0.76596	0.79447	0.76751	0.76176	0.75914	0.79973	0.79834	0.79497		
	4 th week	0.71976	0.78188	0.77145	0.76958	0.70788	0.76197	0.76186	0.75845		
January	1 st week	0.76483	0.814	0.81901	0.81759	0.74663	0.7949	0.79433	0.79521		
	2 nd week	0.76123	0.79204	0.78446	0.78166	0.72418	0.80827	0.80718	0.80789		

Table 49. Beta diversity of arthropods in tomato ecosystem (at ordinal, familial, generic and species level)

Beta diversity indices	Beta diversity									
	Sprayed field					Unsprayed field				
	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
Whittaker's Bw	0.2844	0.40351	0.54791	0.5625	0.22807	0.18519	0.26761	0.26953		
Cody Bc	3.5	15	23.5	24	4	10.5	16.5	16.5		
Routledge's Br	0	0.00876	0.03819	0.04141	0	0.0020197	0.0023725			
Routledge's Bi	0.17317	0.28455	0.34783	0.35375	0.1585	0.14338	0.19681	0.19886		
Routledge's Be	1.1891	1.3292	1.416	1.4244	1.1717	1.1542	1.2175	1.22		
Wilson and Schimida's	0.3211	0.4386	0.5774	0.57692	0.35088	0.25926	0.33199	0.32227		

Table 38. Diversity of arthropods in tomato ecosystem

Order	Family	Genus	Unsprayed	Sprayed	Total	
Araneae	Araneidae	<i>Argiope</i> sp.	11	9	20	
		<i>Neoscona theisi</i> (Walckenaer)	14	9	23	
	Salticidae	<i>Plexippus paykulli</i> (Audouin)	7	4	11	
		<i>Harmochirus brachiatus</i> (Thorell)	4	2	6	
	Oxyopidae	<i>Peucetia viridana</i> (Hentz)	12	7	19	
	Lycosidae	<i>Pardosa birmanica</i> Simon	7	2	9	
		<i>Pardosa</i> sp.	26	14	40	
	Tetragnathidae	<i>Tetragnatha</i> sp.	13	9	22	
		Unidentified spider sp. 1	9	5	14	
	Acarina	Unidentified spider sp. 2	8	5	13	
		<i>Tetranychus urticae</i> Koch	17	8	25	
	Orthoptera	Pyrgomorphidae	<i>Atractomorpha similis</i> Bolívar	13	8	21
		Acrididae	<i>Trilophidia annulata</i> Thunberg	13	8	21
			Unidentified grasshopper sp.	12	8	20
Gryllidae		<i>Gryllus</i> sp.	13	8	21	
Tettigoniidae		<i>Phaneroptera gracilis</i> Burmeister	11	6	17	
Tridactylidae		<i>Tridactylus</i> sp.	16	11	27	
Blattidae	<i>Blattella germanica</i> (Linnaeus)	7	4	11		
Odonata	Libellulidae	<i>Pantala flavescens</i> (Fabricius)	12	10	22	
Hemiptera	Cicadellidae	<i>Amrasca biguttula biguttula</i> (Ishida)	54	39	93	
		<i>Aphis gossypii</i> Glover	136	72	208	

Order	Family	Genus	Unsprayed	Sprayed	Total	
	Aleyrodidae	<i>Bemisia tabaci</i> (Gennadius)	62	47	109	
		<i>Aleurodicus dispersus</i> Russell	20	13	33	
	Pentatomidae	<i>Nezara viridula</i> (Linnaeus)	11	5	16	
		<i>Macrolophus</i> sp.	112	61	173	
	Anthocoridae	<i>Orius insidiosus</i> (Say)	8	5	13	
	Membracidae	<i>Oxyrachis</i> sp.	11	5	16	
	Coreidae	<i>Cletus bipunctatus</i> Westd	10	5	15	
		<i>Nisia atrovonosa</i> (Motschulsky)	19	10	29	
	Lygaeidae	<i>Oxycarenus hyalinipennis</i> (Costa)	6	2	8	
		<i>Lygaeus hospes</i> (Fabricius)	11	4	15	
	Delphacidae	<i>Peregrinus maidis</i> (Ashmead)	32	21	53	
		<i>Odontotermes obesus</i> (Rambur)	7	3	10	
	Dermaptera	Labiduridae	<i>Labidura</i> sp.	9	9	18
			<i>Thrips tabaci</i> (Lindeman)	45	40	85
Diptera	Muscidae	<i>Musca domestica</i> Linnaeus	61	55	116	
	Agromyzidae	<i>Liriomyza trifolii</i> (Burgess)	207	78	285	
	Sepsidae	<i>Sepsis</i> sp.	15	6	21	
	Tipulidae	<i>Tipula</i> sp.	23	13	36	
Hymenoptera	Formicidae	<i>Solenopsis geminata</i> (Fabricius)	105	73	178	
		<i>Camponotus compressus</i> (Fabricius)	103	47	150	
	Megachilidae	<i>Megachile</i> sp.	15	10	25	

Order	Family	Genus	Unsprayed	Sprayed	Total
Lepidoptera	Apidae	<i>Apis cerana indica</i> Fabricius	13	12	25
		<i>Apis dorsata</i> Fabricius	19	12	31
	Vespidae	<i>Polistes</i> sp.	7	5	12
		<i>Delta camponiforme</i> (Fabricius)	8	6	14
	Noctuidae	<i>Spodoptera litura</i> (Fabricius)	21	12	33
		<i>Helicoverpa armigera</i> Hubner	58	30	88
		<i>Trichoplusia ni</i> (Hubner)	7	3	10
		<i>Danaus chrysippus</i> (Linnaeus)	9	8	17
	Nymphalidae	<i>Ergolis merione</i> (Cramer)	5	4	9
		<i>Lampides boeticus</i> (Linnaeus)	7	5	12
Lycaenidae	<i>Lampides boeticus</i> (Linnaeus)	7	5	12	
	Unidentified moth sp.	8	5	13	
Coleoptera	Curculionidae	<i>Myllocerus</i> sp.	65	57	122
	Scarabaeidae	<i>Oxyetomia versicolor</i> (Fabricius)	9	6	15
	Coccinellidae	<i>Cheilomenes sexmaculata</i> (Fabricius)	90	73	163
		<i>Chilocorus nigritus</i> (Fabricius)	3	1	4
	Chrysomelidae	<i>Micraspis discolor</i> (Fabricius)	10	4	14
		<i>Zygogramma bicolorata</i> Pallister	11	8	19
		<i>Aulacophora foveicollis</i> (Lucas)	15	7	22
		<i>Epirix cucumeris</i> (Harris)	4	2	6
		<i>Chiridopsis bipunctata</i> (Linnaeus)	9	3	12
	Tenebrionidae	<i>Alphitobius</i> sp.	19	14	33
Staphylinidae	<i>Paederus</i> sp.	5	2	7	
Neuroptera	Chrysopidae	<i>Chrysoperla zaastrowi silleni</i> (Esben - Petersen)	8	4	12
	Total		1717	1043	2760



Argiope sp.



Clubiona sp.



Tetragnatha javana
(Thorell)



Tetragnatha sp.



Peucetia viridana (Hentz)



Philodromus rufus
Walckenaer

**Plate 15a. Photo inventory of arthropods in rice ecosystem
(Order: Araneae)**



Plexippus paykulli
(Audouin)



Plexippus paykulli
(Audouin)



Neoscona sp.



Oxyopes javanus Thorell



Oxyopes sp.

**Plate 15b. Photo inventory of arthropods in rice ecosystem
(Order: Araneae)**



Thomisus sp.



Unidentified spider sp. 1



Hippasa sp.



Unidentified spider sp. 2



Lycosa sp.



Tylorida striata (Thorell)



Pardosa sp.



Pardosa birmanica Simon

**Plate 15c. Photo inventory of arthropods in rice ecosystem
(Order: Araneae)**

**Plate 15d. Photo inventory of arthropods in rice ecosystem
(Order: Araneae)**



Adalia bipunctata
(Linnaeus)



Cheilomenes sexmaculata
(Fabricius)



Micraspis discolor
(Fabricius)



Harmonia octomaculata
(Fabricius)



Leptispa pygmaea Baly

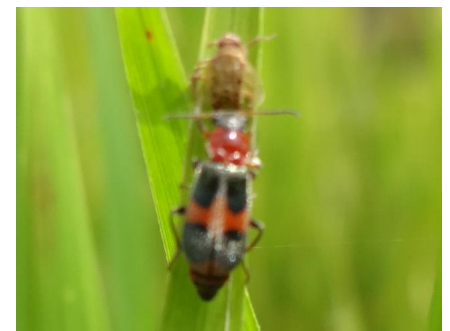


Ophionea nigrofasciata
(Schmidt-Goebel)

**Plate 16. Photo inventory of arthropods in rice ecosystem
(Order: Coleoptera)**



Paederus fuscipes Curtis



Apalochrus sp.



Myllocerus sp.



Rivellia sp.



Tipula sp.



Hedriodiscus sp.

**Plate 17. Photo inventory of arthropods in rice ecosystem
(Order: Coleoptera and Diptera)**



Polytoxus fuscovittatus
(Stal)



Leptocorisa oratorius
(Fabricius)



Nilaparvata lugens (Stal)



Sogatella furcifera (Horvath)



Eysarcoris sp.



Linnogonus fossarum
(Fabricius)



Nephotettix virescens
(Distant)



Recilia dorsalis
(Motschulsky)



Pygomenida varipennis (Westwood)



Cofana spectra
(Distant)

**Plate 18a. Photo inventory of arthropods in rice ecosystem
(Order: Hemiptera)**

**Plate 18b. Photo inventory of arthropods in rice ecosystem
(Order: Hemiptera)**



Amrasca biguttula biguttula
(Ishida)



Cletus bipunctatus Westd



Cerceris sp.



Scirpophaga incertulas
Walker



Pyrilla perpusilla Walker



Microctonus hyperodae Loan



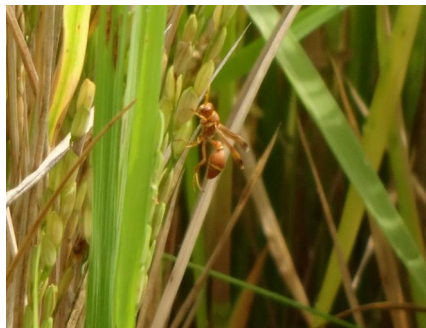
Parapoynx stagnalis Zeller



Pelopidas mathias Fabricius



Camponotus sp.



Ropalidia spatulata Vecht



Cnaphalocrocis medinalis
Guenee



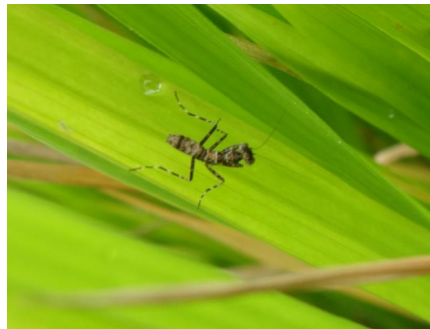
Lampides boeticus
(Linnaeus)

**Plate 19. Photo inventory of arthropods in rice ecosystem
(Order: Hemiptera and Hymenoptera)**

**Plate 20. Photo inventory of arthropods in rice ecosystem
(Order: Hymenoptera and Lepidoptera)**



Otheris sp.



Mantis sp.



Orthetrum sabina
(Drury)



Diplacodes trivialis
(Rambur)



Agriocnemis rubricauda Tillyard



Ceriagrion rubiae Laidlaw



Oxya sp.



Conocephalus longipennis
(Haan)



Ischnura aurora (Brauer)



Crocothemis servilia (Drury)



Anaxipha longipennis (Serville)

**Plate 21. Photo inventory of arthropods in rice ecosystem
(Order: Lepidoptera, Mantidae and Odonata)**

**Plate 22. Photo inventory of arthropods in rice ecosystem
(Order: Odonata and Orthoptera)**



Gryllus sp.



Neorthacris simulans
(Bolivar)



Myrmeleon sp.

**Plate 23. Photo inventory of arthropods in rice ecosystem
(Order: Orthoptera and Neuroptera)**

Table 50. Diversity of arthropods in rice ecosystem

Order	Family	Genus	Unsprayed	Sprayed	Total	
Araneae	Araneidae	<i>Argiope</i> sp.	19	13	32	
		<i>Neoscona</i> sp.	16	10	26	
	Clubionidae	<i>Clubiona</i> sp.	18	10	28	
		<i>Lycosa</i> sp.	14	9	23	
	Lycosidae	Unidentified spider sp.1	11	7	18	
		<i>Pardosa</i> sp.	14	9	23	
		<i>Pardosa birmanica</i> Simon, 1884	7	3	10	
		<i>Hippasa</i> sp.	16	10	26	
		<i>Oxyopes javanus</i> Thorell	18	12	30	
		<i>Oxyopes</i> sp.	13	9	22	
		<i>Peucetia viridana</i> (Hentz)	10	3	13	
		<i>Philodromus rufus</i> Walckenaer	3	2	5	
		<i>Plexippus paykulli</i> (Audouin)	12	9	21	
		Tetragnathidae	<i>Tetragnatha javana</i> (Thorell)	44	34	78
	<i>Tetragnatha</i> sp.		13	6	19	
	Thomisidae	<i>Tylorida striata</i> (Thorell)	16	12	28	
		<i>Thomisus</i> sp.	11	8	19	
			Unidentified spider sp.2	13	8	21

Order	Family	Genus	Unsprayed	Sprayed	Total	
Orthoptera	Acrididae	<i>Oxya</i> sp.	15	10	25	
		<i>Acrida turricata</i> (Linnaeus)	4	2	6	
		<i>Acrida exaltata</i> (Walker)	8	5	13	
	Tettigoniidae	<i>Conocephalus longipennis</i> (Haan)	6	5	11	
		<i>Anaxipha longipennis</i> (Serville)	6	4	10	
	Gryllidae	<i>Gryllus</i> sp.	7	7	14	
		<i>Neorthacris simulans</i> (Bolivar)	5	3	8	
	Mantodea	Pygomorphaeidae	<i>Mantis</i> sp.	4	2	6
		Coenagrionidae	<i>Agrionemis rubricauda</i> Tillyard	81	75	156
	Hemiptera	Libellulidae	<i>Ceriatrion rubiae</i> Laidlaw	15	9	24
			<i>Ischnura aurora</i> (Brauer)	13	8	21
			<i>Enallagma</i> sp.	9	6	15
			<i>Crocothemis servilia</i> (Drury)	32	21	53
<i>Orthetrum sabina</i> (Drury)			41	31	72	
<i>Brachythemis contaminata</i> (Fabricius)			26	18	44	
<i>Diplacodes trivialis</i> (Rambur)			14	10	24	
<i>Polytoxus fuscovittatus</i> (Stal)			34	31	65	
<i>Limnogonus fossarum</i> (Fabricius)			68	65	133	

Order	Family	Genus	Unsprayed	Sprayed	Total
Orthoptera	Miridae	<i>Cyrtorhinus lividipennis</i> Reuter	71	39	110
	Alydidae	<i>Leptocoris oratorius</i> (Fabricius)	155	119	274
	Pentatomidae	<i>Pygomenida varipennis</i> (Westwood)	88	58	146
		<i>Eysarcoris</i> sp.	45	37	82
		<i>Nezara viridula</i> (Linnaeus)	26	18	44
		<i>Scotinophara lurida</i> (Burmeister)	7	4	11
		Unidentified stink bug sp.	11	9	20
	Delphacidae	<i>Nilaparvata lugens</i> (Stal)	211	111	322
		<i>Sogatella furcifera</i> (Horvath)	143	76	219
		<i>Nephotettix cincticeps</i> (Uhler)	92	63	155
	Cicadellidae	<i>Nephotettix virescens</i> (Distant)	141	106	247
		<i>Recilia dorsalis</i> (Motschulsky)	109	83	192
		<i>Cofana spectra</i> (Distant)	87	54	141
<i>Amrasca biguttula biguttula</i> (Ishida)		36	20	56	
<i>Nista atrovenosa</i> (Motschulsky).		50	32	82	
Coreidae	<i>Cletus bipunctatus</i> Westd	7	4	11	
	<i>Pyrilla perpusilla</i> Walker	6	6	12	
Dermaptera	Unidentified ear wig sp.	19	13	32	
	<i>Musca</i> sp.	13	6	19	
Diptera	Tachinidae	<i>Argyrophylax nigroitalis</i> (Baranov)	11	9	20

Order	Family	Genus	Unsprayed	Sprayed	Total
Hymenoptera	Satromyidae	<i>Hedriodiscus</i> sp.	41	33	74
	Platystomatidae	<i>Rivellia</i> sp.	7	3	10
	Tipulidae	<i>Tipula</i> sp.	17	10	27
	Syrphidae	<i>Syrpha</i> sp.	7	5	12
	Ichneumonidae	<i>Xanthopimpla flavolineata</i> Cameron	25	12	37
	Braconidae	<i>Microctonus hyperodae</i> Loan	5	1	6
	Apidae	<i>Apis</i> sp.	14	7	21
		<i>Apis dorsata</i> Fabricius	52	31	83
	Formicidae	<i>Camponotus</i> sp.	132	97	229
		<i>Solenopsis geminata</i> (Fabricius)	181	141	322
	Vespidae	<i>Ropalidia spatulata</i> Vecht	24	15	39
		<i>Vespa cincta</i> Drury	2	1	3
	Crabronidae	<i>Cerceris</i> sp.	7	3	10
		<i>Scirpophaga incertulas</i>			
Lepidoptera	Crambidae	Walker	102	55	157
		<i>Parapoynx stagnalis</i> Zeller	72	43	115
	Lycaenidae	<i>Lampides boeticus</i> (Linnaeus)	5	1	6
	Noctuidae	<i>Otheris</i> sp.	1	0	1
	Hesperiidae	<i>Pelopidas mathias</i> Fabricius	74	48	122

Order	Family	Genus	Unsprayed	Sprayed	Total
Coleoptera	Satyridae	<i>Melanitis leda</i> Linnaeus	2	0	2
	Pyralidae	<i>Cnaphalocrocis medinalis</i> Guenee	56	38	94
	Coccinellidae	<i>Adalia bipunctata</i> (Linnaeus)	29	20	49
		<i>Cheilomenes sexmaculata</i> (Fabricius)	16	11	27
		<i>Micraspis discolor</i> (Fabricius)	10	5	15
		<i>Harmonia octomaculata</i> (Fabricius)	7	5	12
	Chrysomelidae	<i>Leptispa pygmaea</i> Baly	70	53	123
		<i>Menolepta</i> sp.	3	2	5
		<i>Aulacophora foveicollis</i> (Lucas)	9	4	13
	Carabidae	<i>Ophionea nigrofasciata</i> (Schmidt-Goebel)	27	23	50
	Staphylinidae	<i>Paederus fuscipes</i> Curtis	35	26	61
	Melyridae	<i>Apalochrus</i> sp.	4	2	6
	Curculionidae	<i>Myllocerus</i> sp.	9	6	15
	Elateridae	Unidentified click beetle sp. 1	2	3	5
Lampyridae	Unidentified sp. 2	2	1	3	
Myrmeleontidae	<i>Myrmeleon</i> sp.	3	1	4	
	Total	3036	2059	5095	

Table 51. Arthropod diversity in rice ecosystem - Alpha diversity (Species number)

Month	Sampling week	Species richness indices (Species number)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
October	1 st week	9	42	63	68	11	51	80	87		
	2 nd week	9	38	57	61	9	45	72	78		
	3 rd week	9	39	59	63	10	42	64	70		
	4 th week	9	40	59	63	10	44	68	73		
November	1 st week	9	36	56	60	10	44	68	73		
	2 nd week	10	38	55	59	9	40	64	70		
	3 rd week	9	36	59	62	9	39	64	69		
	4 th week	10	39	61	63	10	39	58	61		
December	1 st week	10	43	68	73	10	47	73	79		

Table 52. Arthropod diversity in rice ecosystem - Alpha diversity (Fishers alpha)

Month	Sampling week	Species richness indices (Fishers alpha)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
October	1 st week	1.9159	15.824	30.615	35.03	2.1659	16.483	32.576	37.302		
	2 nd week	1.9234	13.689	26.077	29.273	1.6934	13.828	27.744	31.458		
	3 rd week	1.9577	14.738	28.972	32.538	1.9271	12.528	23.121	26.512		
	4 th week	1.9159	14.686	27.368	30.615	1.9462	13.612	25.935	28.972		
November	1 st week	1.931	12.713	25.567	28.755	1.9245	13.346	25.278	28.209		
	2 nd week	2.1522	13.159	23.342	26.191	1.7146	11.97	23.814	27.361		
	3 rd week	1.8901	12.226	26.428	28.726	1.6877	11.244	22.985	25.771		
December	4 th week	2.0988	13.073	26.04	27.452	1.9245	11.269	19.898	21.448		
	1 st week	1.9192	12.859	25.126	28.03	1.9934	15.639	30.71	34.962		

Table 53. Arthropod diversity in rice ecosystem - Alpha diversity (Q Statistic)

Month	Sampling week	Species richness indices (Q Statistic)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
October	1 st week	4.0782	15.533	24.886	27.051	2.4423	16.11	30.445	33.863		
	2 nd week	2.7873	12.557	21.64	23.444	4.2146	12.984	24.836	27.068		
	3 rd week	3.641	13.116	23.083	23.804	2.8825	14.427	21.552	21.766		
	4 th week	3.641	12.557	23.211	25.487	2.6935	13.297	21.07	25.785		
November	1 st week	2.4122	11.441	19.572	20.919	3.1067	12.743	20.042	22.603		
	2 nd week	3.7453	12.837	19.572	20.193	3.1357	11.15	18.274	20.042		
	3 rd week	3.2464	10.82	22.722	23.444	2.5251	13.706	21.487	25.164		
	4 th week	2.6712	10.923	20.193	21.125	2.6712	10.563	15.929	16.831		
December	1 st week	2.4653	12.022	20.299	22.883	2.5328	12.061	25.475	28.271		

Table 54. Arthropod diversity in rice ecosystem - Alpha diversity (Margalef's D)

Month	Sampling week	Species richness indices (Margalef's D)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
October	1 st week	1.4975	7.6745	11.605	12.541	1.7096	8.548	13.506	14.703		
	2 nd week	1.5015	6.9446	10.511	11.262	1.3697	7.5334	12.156	13.183		
	3 rd week	1.5201	7.2206	11.021	11.781	1.5402	7.0163	10.781	11.808		
	4 th week	1.4975	7.3002	10.857	11.605	1.5512	7.4111	11.548	12.409		
November	1 st week	1.5057	6.5874	10.352	11.104	1.5386	7.3513	11.454	12.309		
	2 nd week	1.6645	6.8428	9.9867	10.726	1.3824	6.7394	10.887	11.923		
	3 rd week	1.4832	6.4891	10.753	11.31	1.3663	6.4901	10.76	11.614		
	4 th week	1.636	6.9075	10.907	11.27	1.5386	6.4965	9.7447	10.258		
December	1 st week	1.5356	7.1663	11.432	12.285	1.5779	8.0648	12.623	13.675		

Table 55. Arthropod diversity in rice ecosystem - Alpha diversity (Shannon - Weiner index)

Month	Sampling week	Species richness (Shannon - Weiner index)															
		Sprayed field						Unsprayed field									
		Ordinal level		Familial level		Generic level		Species level		Ordinal level		Familial level		Generic level		Species level	
		H	Variance H	H	Variance H	H	Variance H	H	Variance H	H	Variance H	H	Variance H	H	Variance H	H	Variance H
October	1 st week	1.7705	0.003673	3.1606	0.0055746	3.7461	0.0043779	3.8454	0.0041391	1.7946	0.0025094	3.2863	0.003603	3.9549	0.0026929	4.9524	0.0026416
	2 nd week	1.6868	0.004112	3.0279	0.0057136	3.6427	0.0042788	3.7286	0.0041652	1.6884	0.0024155	3.1628	0.0034609	3.8209	0.0027434	3.9208	0.0026319
	3 rd week	1.7599	0.00379	3.1528	0.0054997	3.6967	0.0046398	3.7608	0.0041789	1.7203	0.0026387	3.1288	0.0033851	3.721	0.0025502	3.8052	0.0025501
	4 th week	1.675	0.004214	3.0534	0.0059284	3.6039	0.0047586	3.6752	0.0046572	1.7467	0.0024463	3.1713	0.0034327	3.7346	0.0029217	3.8181	0.0028857
November	1 st week	1.6904	0.0037	3.0104	0.0054318	3.586	0.0046422	3.652	0.0047541	1.7085	0.002399	3.1027	0.003584	3.7009	0.0028642	3.7776	0.0028651
	2 nd week	1.6842	0.004353	3.0214	0.0054519	3.5618	0.0042636	3.6331	0.0043237	1.6218	0.0028652	3.0789	0.003268	3.6673	0.0028669	3.7332	0.0030161
	3 rd week	1.7446	0.003534	3.0839	0.0043656	3.6282	0.0045443	3.7083	0.0041888	1.5848	0.0029298	2.99	0.0035647	3.6097	0.0031088	3.7068	0.0028357
	4 th week	1.7517	0.003533	3.1573	0.0037244	3.6967	0.0034445	3.7413	0.0033927	1.557	0.0033731	2.8981	0.0039654	3.4867	0.0029949	3.547	0.0029575
December	1 st week	1.5186	0.003312	2.8609	0.0040124	3.5889	0.0034091	3.6797	0.0033084	1.784	0.0026454	3.2848	0.0031233	3.8823	0.0027737	3.9899	0.0028519

Table 56. Arthropod diversity in rice ecosystem - Alpha diversity (Brillouin diversity index)

Month	Sampling week	Species richness indices (Brillouin diversity index)											
		Sprayed field						Unsprayed field					
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level
October	1 st week	1.6902	2.8796	3.3487	3.4241	1.7349	3.063	3.624	3.6997	1.6362	2.9598	3.5159	3.5962
	2 nd week	1.5895	2.7679	3.2707	3.336	1.6362	2.9598	3.5159	3.5962	1.6641	2.934	3.4413	3.5077
	3 rd week	1.6759	2.8668	3.2945	3.3681	1.6641	2.934	3.4413	3.5077	1.689	2.9645	3.4376	3.504
	4 th week	1.5972	2.788	3.235	3.2872	1.689	2.9645	3.4376	3.504	1.6128	2.7566	3.4174	3.4785
November	1 st week	1.6064	2.7749	3.2227	3.2763	1.5692	2.8871	3.382	3.4308	1.6689	2.8393	3.34	3.421
	2 nd week	1.6064	2.7749	3.2227	3.2763	1.5692	2.8871	3.382	3.4308	1.6689	2.8393	3.34	3.421
	3 rd week	1.6678	2.9185	3.353	3.3881	1.5031	2.7228	3.2391	3.2893	1.6778	2.9185	3.353	3.3881
	4 th week	1.4666	2.7766	3.3161	3.3902	1.7204	3.0527	3.541	3.6058				
December	1 st week	1.4666	2.7766	3.3161	3.3902	1.7204	3.0527	3.541	3.6058				

Table 57. Arthropod diversity in rice ecosystem - Alpha diversity (Simpson's index)

Month	Sampling week	Species dominance indices (Simpson's index)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
October	1 st week	4.3726	16.656	35.516	41.72	4.3191	17.656	40.782	46.392		
	2 nd week	3.8757	14.552	32.139	36.094	3.8988	15.928	35.433	40.715		
	3 rd week	4.3999	16.859	33.934	41.082	3.945	15.239	32.356	35.855		
	4 th week	3.8731	14.491	30.022	32.201	4.2262	16.366	32.393	35.907		
November	1 st week	4.1179	14.49	29.671	31.738	4.0658	14.717	30.88	33.612		
	2 nd week	3.7872	14.04	27.906	30.004	3.6307	15.454	30.871	32.863		
	3 rd week	4.2152	16.321	29.271	33.739	3.3469	13.051	26.681	30.904		
	4 th week	4.1537	18.248	34.317	36.274	3.1392	11.507	24.304	26.044		
December	1 st week	3.0378	12.151	25.626	28.974	4.3897	20.929	41.489	45.121		

Table 58. Arthropod diversity in rice ecosystem - Alpha diversity (Berger Parker diversity index)

Month	Sampling week	Species dominance indices (Berger Parker diversity index)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
October	1 st week	0.41627	0.15311	0.08612	0.07177	0.42363	0.14697	0.07493	0.05764		
	2 nd week	0.45146	0.15534	0.08738	0.08738	0.45349	0.15116	0.07849	0.06105		
	3 rd week	0.41451	0.1658	0.09845	0.057	0.45217	0.14783	0.08116	0.08116		
	4 th week	0.44976	0.16268	0.08612	0.08612	0.42296	0.15106	0.07855	0.07251		
November	1 st week	0.42857	0.16256	0.08867	0.08867	0.42939	0.15274	0.08357	0.08357		
	2 nd week	0.46188	0.14798	0.08969	0.08969	0.47546	0.15337	0.07976	0.07669		
	3 rd week	0.43182	0.15909	0.1	0.09091	0.5043	0.18338	0.10029	0.08596		
	4 th week	0.43673	0.11429	0.08163	0.08163	0.52738	0.18444	0.10951	0.10951		
December	1 st week	0.53846	0.19088	0.10256	0.08262	0.41667	0.1	0.06667	0.06667		

Table 59. Arthropod diversity in rice ecosystem - (McIntosh, 1967)

Month	Sampling week	Species dominance indices (McIntosh, 1967)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
October	1 st week	0.55642	0.80139	0.87973	0.8925	0.54583	0.79928	0.88203	0.89175		
	2 nd week	0.5251	0.784	0.87146	0.88134	0.51943	0.78646	0.87075	0.88204		
	3 rd week	0.55935	0.80456	0.87742	0.89281	0.52251	0.78063	0.86284	0.87169		
	4 th week	0.52469	0.78313	0.86507	0.87135	0.54093	0.7906	0.86363	0.8725		
November	1 st week	0.54144	0.78371	0.86456	0.87064	0.53034	0.77588	0.85855	0.86608		
	2 nd week	0.5176	0.7775	0.85699	0.86377	0.50081	0.78343	0.85956	0.86515		
	3 rd week	0.54621	0.79778	0.86175	0.87443	0.47709	0.75909	0.84462	0.85852		
	4 th week	0.54074	0.80952	0.87389	0.87854	0.45847	0.74053	0.8353	0.84232		
December	1 st week	0.44853	0.74856	0.84051	0.85246	0.55189	0.82171	0.88574	0.89206		

Table 60. Arthropod diversity in rice ecosystem - Alpha diversity (Equitability J)

Month	Sampling week	Evenness indices (Equitability J)									
		Sprayed field					Unsprayed field				
		Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
October	1 st week	0.73837	0.79232	0.84775	0.85456	0.74839	0.82385	0.89501	0.90056		
	2 nd week	0.6951	0.75906	0.82436	0.8286	0.7041	0.79289	0.86468	0.87133		
	3 rd week	0.73393	0.79037	0.83657	0.84243	0.71742	0.78436	0.84207	0.84563		
	4 th week	0.69853	0.76545	0.81559	0.81675	0.72845	0.79501	0.84516	0.8485		
November	1 st week	0.70495	0.75467	0.81152	0.81158	0.71248	0.77782	0.83753	0.83951		
	2 nd week	0.70236	0.75744	0.80604	0.80739	0.67635	0.77209	0.82993	0.82964		
	3 rd week	0.72755	0.7731	0.82131	0.8241	0.66092	0.74957	0.81688	0.82377		
	4 th week	0.73051	0.7915	0.83657	0.83144	0.64933	0.72652	0.78906	0.78826		
December	1 st week	0.6333	0.74227	0.8124	0.81774	0.74399	0.82347	0.87858	0.88202		

Table 61. Beta diversity of arthropods in rice ecosystem (at ordinal, familial, generic and species level)

Beta diversity indices	Beta diversity									
	Sprayed field					Unsprayed field				
	Ordinal level	Familial level	Generic level	Species level	Ordinal level	Familial level	Generic level	Species level		
Whittaker's Bw	0.17857	0.33333	0.35754	0.38462	0.125	0.24297	0.22259	0.22727		
Cody Bc	1.5	9.5	15.5	17.5	0.5	5	6.5	7		
Routledge's Br	0.016807	0.03761	0.03764	0.0403	0	0.0132	0.0079	0.00746		
Routledge's Bi	0.060708	0.17661	0.20698	0.22655	0.07225	0.14537	0.14014	0.14392		
Routledge's Be	1.0626	1.1932	1.23	1.2543	1.0749	1.1565	1.1504	1.1548		
Wilson and Schimida's	0.06071	0.24359	0.25978	0.27535	0.05114	0.11509	0.09575	0.09546		

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26.	Effect of pyridine derivative 20 SC against yellow stem borer damage in rice after first and second spray (Location: Thennamanallur - II season)	
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57.	Arthropod diversity in rice ecosystem - Alpha diversity (Simpson's index)	
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Plate 5. Toxicity of pyridine derivative 20 SC to the eggs of *Chrysoperla zastrowi sillemi* (Esben - Petersen)

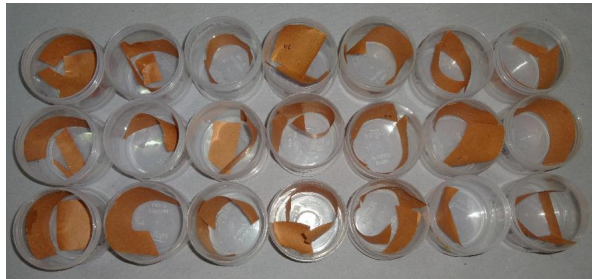


Plate 6. Toxicity of pyridine derivative 20 SC to the grubs of *C. zastrowi sillemi*



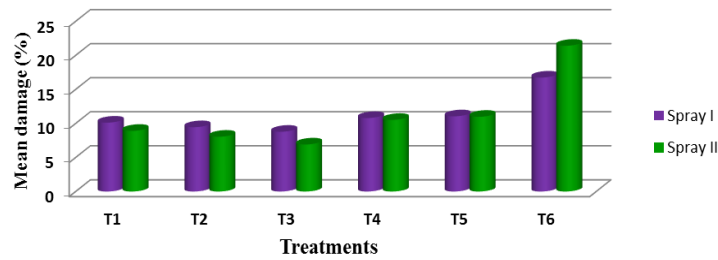
Plate 7. Toxicity of pyridine derivative 20 SC to coccinellid grubs and adults – *Cheilomenes sexmaculata* (Fabricius)



Plate 8. Toxicity of pyridine derivative 20 SC to honey bees

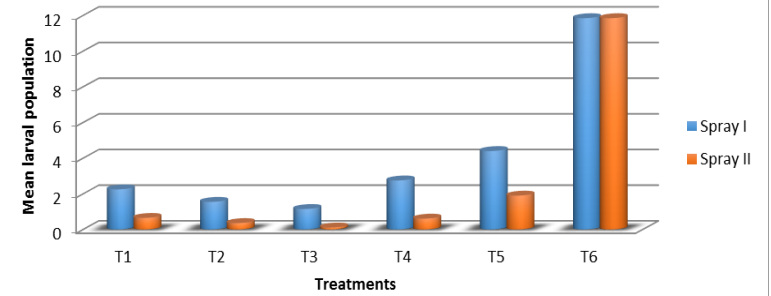


Fig 1. Effect of pyridine derivative 20 SC against tomato fruit borer damage (Location: Thennamanallur - I season)



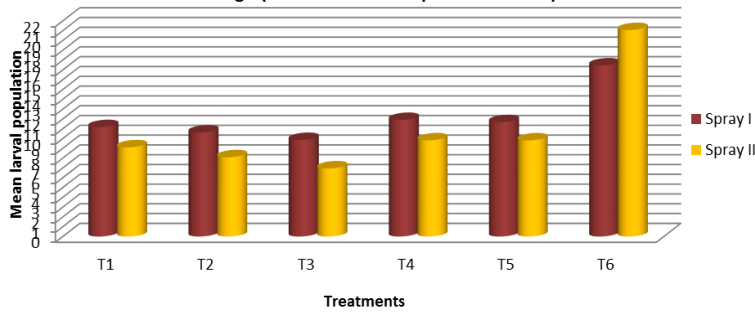
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 3. Effect of pyridine derivative 20 SC on *Helicoverpa armigera* Hubner larvae in tomato (Location: Thennamanallur - I season)



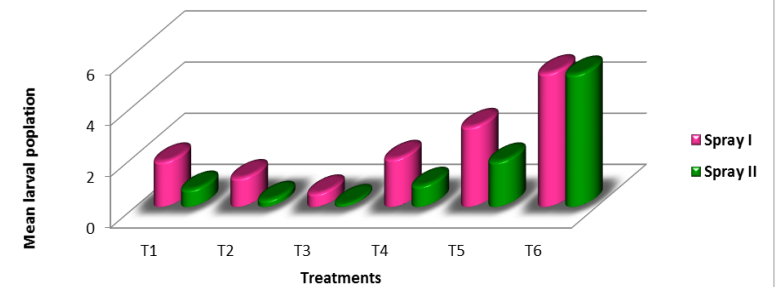
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 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 2. Effect of pyridine derivative 20 SC against tomato fruit borer damage (Location: Mathampatti - II season)



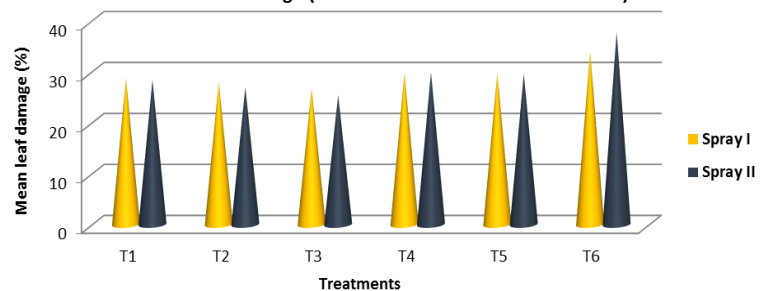
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 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 4. Effect of pyridine derivative 20 SC on *Helicoverpa armigera* Hubner larvae in tomato (Location: Mathampatti - II season)



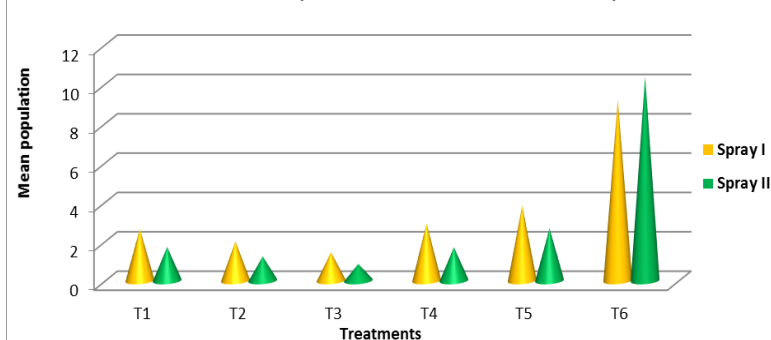
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
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 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 5. Effect of pyridine derivative 20 SC against tomato serpentine leafminer damage (Location: Thennamanallur - I season)



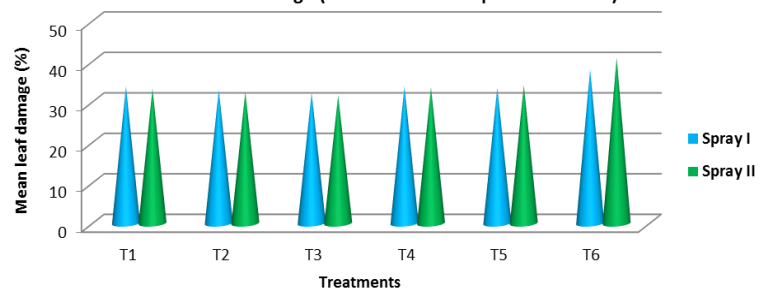
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
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 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 7. Effect of pyridine derivative 20 SC on serpentine leafminer maggots in tomato (Location: Thennamanallur - I season)



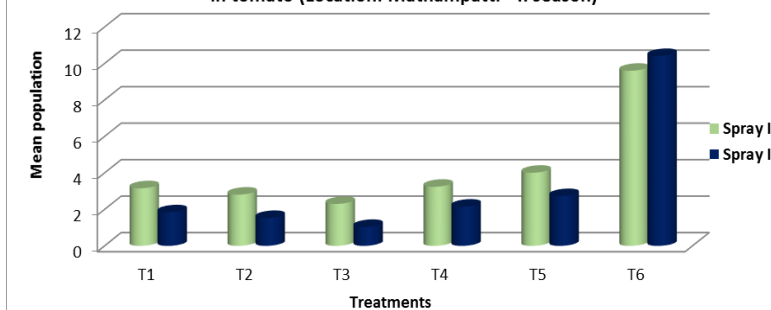
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
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 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 6. Effect of pyridine derivative 20 SC against tomato serpentine leafminer damage (Location: Mathampatti - II season)



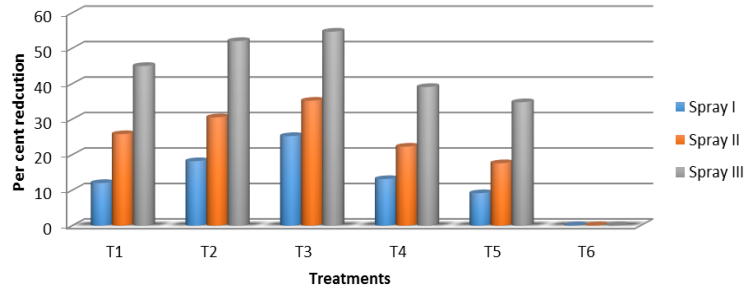
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 8. Effect of pyridine derivative 20 SC on serpentine leafminer maggots in tomato (Location: Mathampatti - II season)



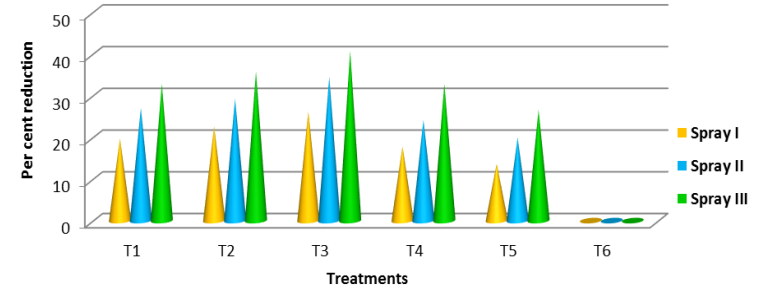
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 9. Effect of pyridine derivative 20 SC against yellow stem borer damage in rice (Location: Poluvampatti - I season)



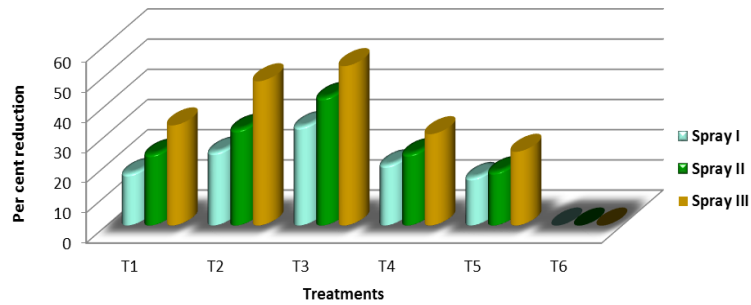
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
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Fig 11. Effect of pyridine derivative 20 SC against leaf folder in rice (Location: Poluvampatti - I season)



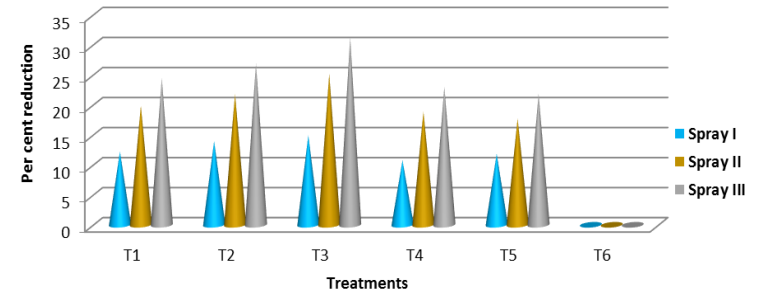
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
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 T5 – Bifenthrin10 EC 50 g a.i. ha⁻¹ T6 – Untreated check

Fig 10. Effect of pyridine derivative 20 SC against yellow stem borer damage in rice (Location: Thennamanallur - II season)



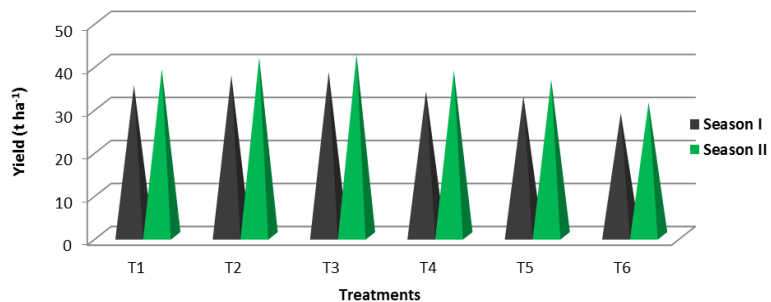
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
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Fig 12. Effect of pyridine derivative 20 SC against leaf folder in rice (Location: Thennamanallur - II season)



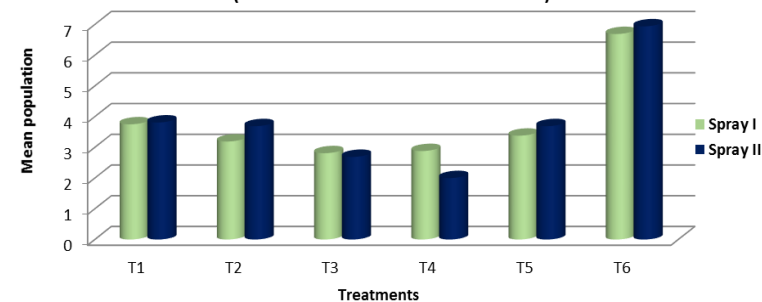
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Bifenthrin10 EC 50 g a.i. ha⁻¹ T6 – Untreated check

Fig 13. Effect of pyridine derivative 20 SC on fruit yield of tomato- season I and II



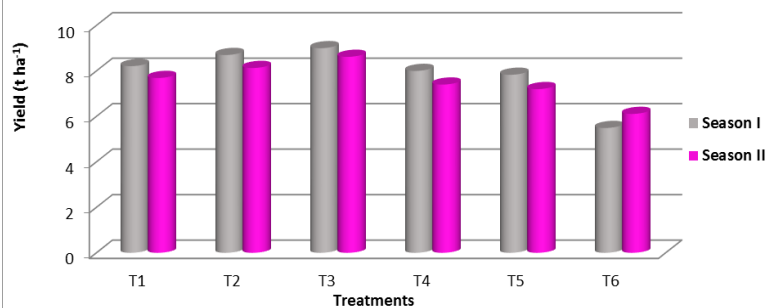
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 15 . Effect of pyridine derivative 20 SC on coccinellids in tomato (Location: Thennamanallur - I season)



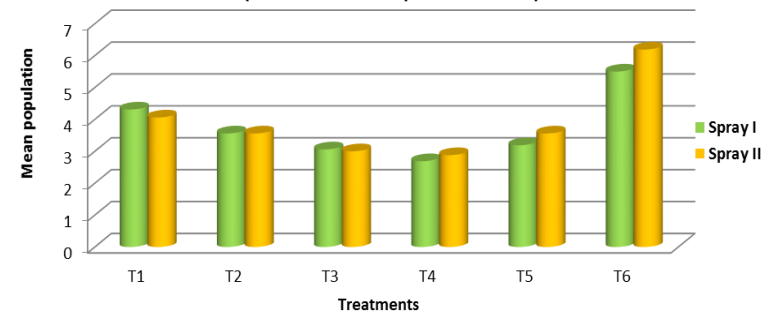
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 14. Effect of pyridine derivative 20 SC on yield of rice - season I and II



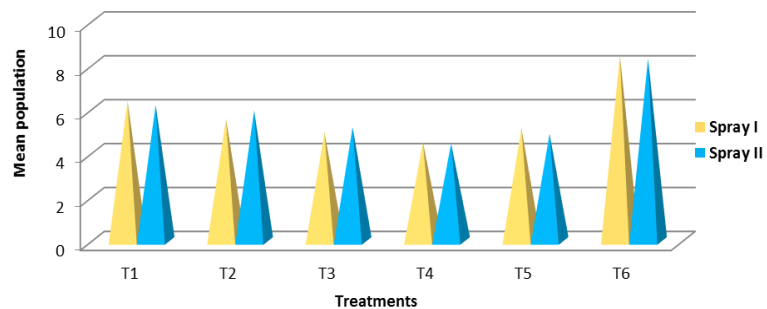
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Bifenthrin10 EC 50 g a.i. ha⁻¹ T6 – Untreated check

Fig 16 . Effect of pyridine derivative 20 SC on coccinellids in tomato (Location: Mathampatti - II season)



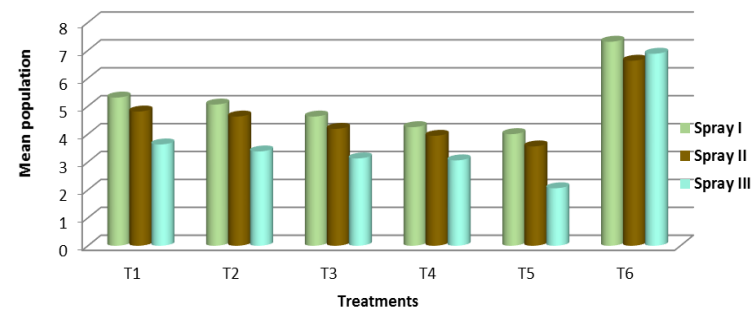
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 17. Effect of pyridine derivative 20 SC on spiders in tomato (Location: Thennamanallur - I season)



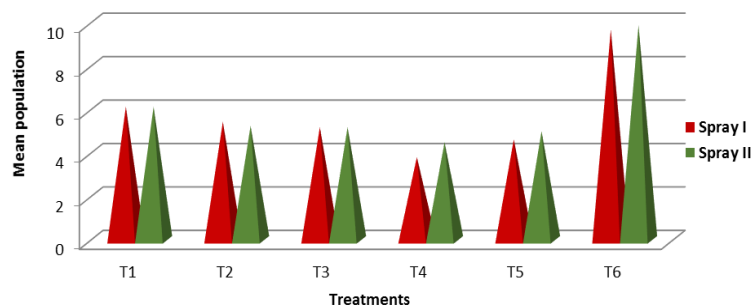
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 19. Effect of pyridine derivative 20 SC on spiders in rice (Location: Poluvampatti - I season)



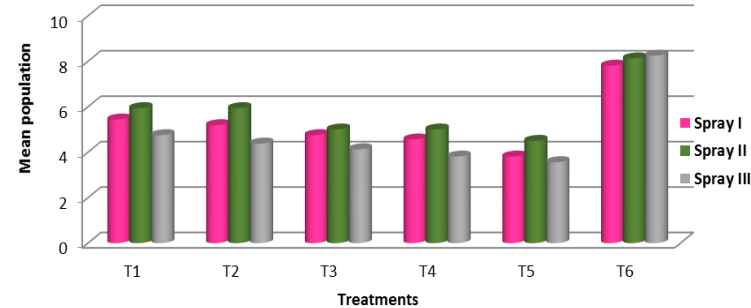
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Bifenthrin10 EC 50 g a.i. ha⁻¹ T6 – Untreated check

Fig 18. Effect of pyridine derivative 20 SC on spiders in tomato (Location: Mathampatti - II season)



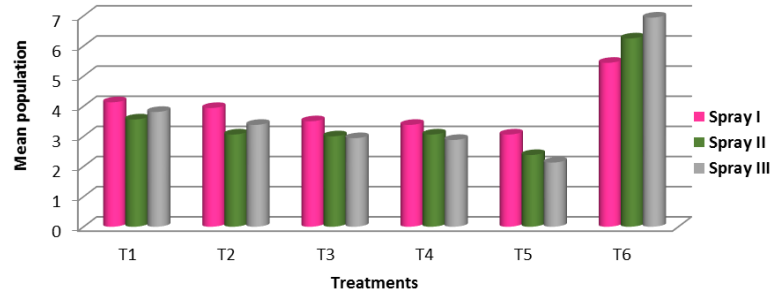
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron 10 EC 75 g a.i. ha⁻¹ T6 – Untreated check

Fig 20. Effect of pyridine derivative 20 SC on spiders in rice (Location: Thennamanallur - II season)



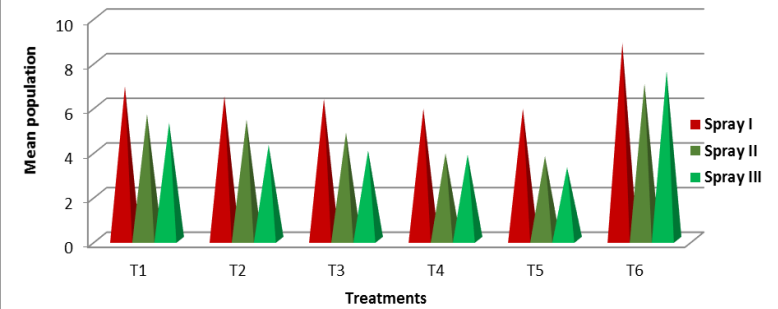
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Bifenthrin10 EC 50 g a.i. ha⁻¹ T6 – Untreated check

Fig 21. Effect of pyridine derivative 20 SC on mirids in rice (Location: Poluvampatti - I season)



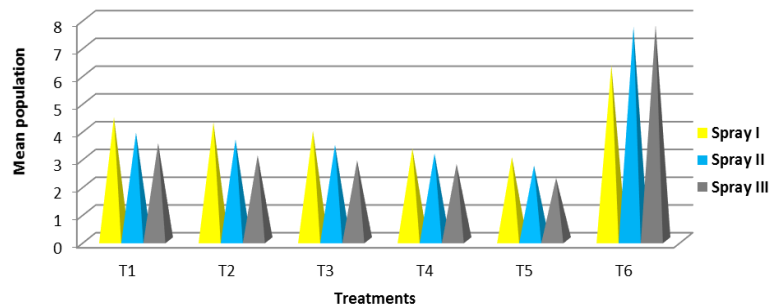
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantranilprole 20 SC 30 g a.i. ha⁻¹
 T5 – Bifenthrin10 EC 50 g a.i. ha⁻¹ T6 – Untreated check

Fig 23. Effect of pyridine derivative 20 SC on rove beetle in rice (Location: Poluvampatti - I season)



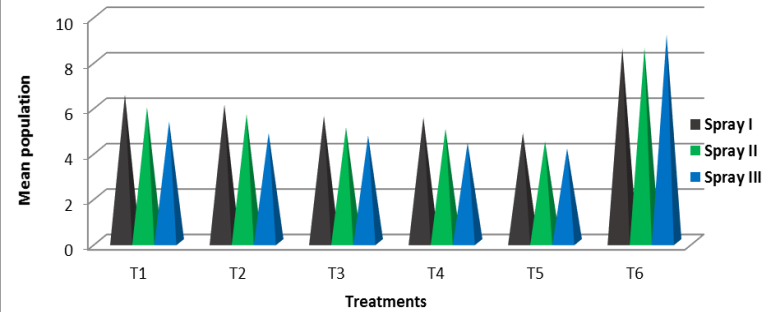
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
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 T5 – Bifenthrin10 EC 50 g a.i. ha⁻¹ T6 – Untreated check

Fig 22. Effect of pyridine derivative 20 SC on mirids in rice (Location: Thennamanallur - II season)



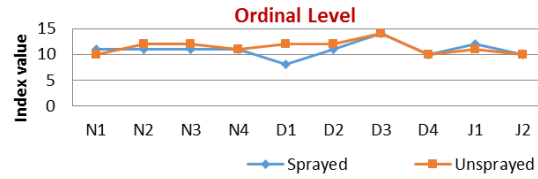
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantranilprole 20 SC 30 g a.i. ha⁻¹
 T5 – Bifenthrin10 EC 50 g a.i. ha⁻¹ T6 – Untreated check

Fig 24. Effect of pyridine derivative 20 SC on rove beetle in rice (Location: Thennamanallur - II season)

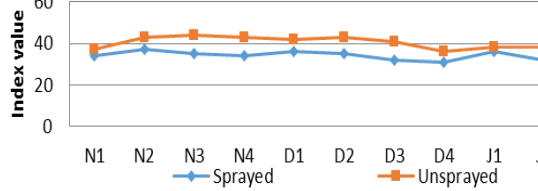


T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
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 T5 – Bifenthrin10 EC 50 g a.i. ha⁻¹ T6 – Untreated check

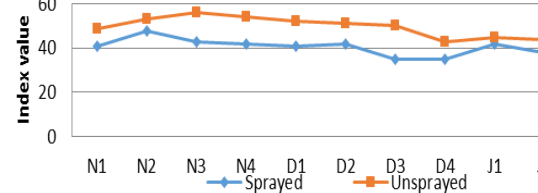
Fig.25 Arthropod diversity based on Species number in tomato ecosystem



Family Level



Generic Level



Species Level

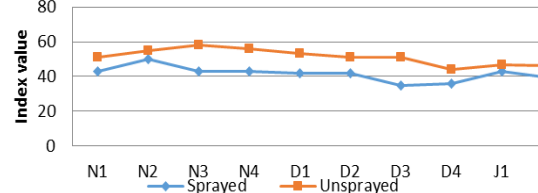
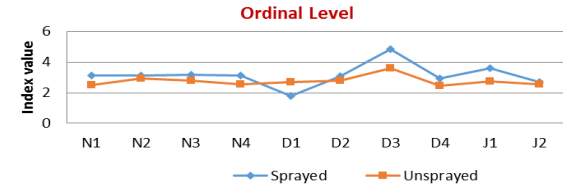
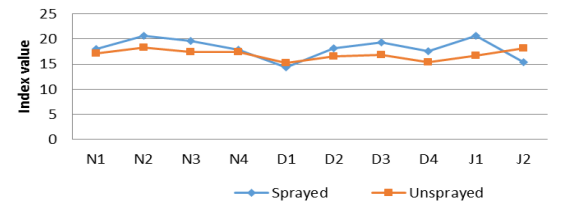


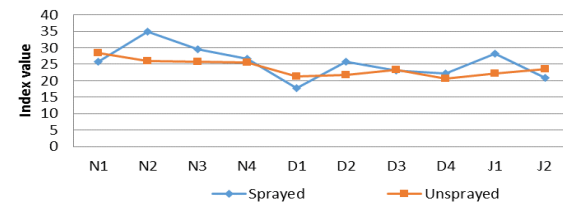
Fig.26. Arthropod diversity based on Fishers Alpha in tomato ecosystem



Family Level



Generic Level



Species Level

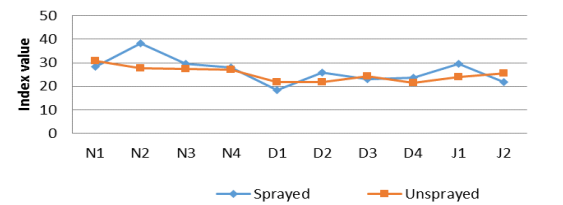


Fig 27. Arthropod diversity based on Q Statistic in tomato ecosystem

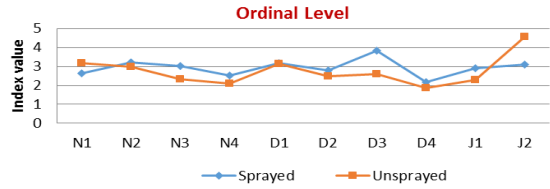
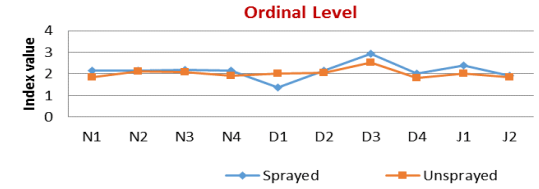
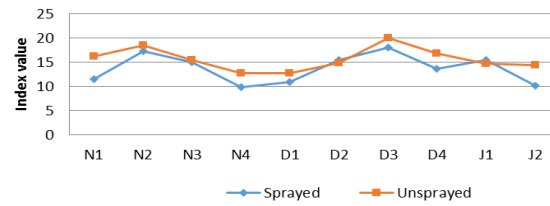


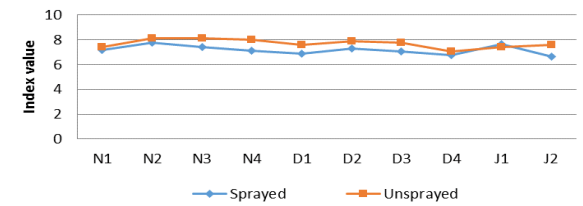
Fig 28. Arthropod diversity based on Margalef's D in tomato ecosystem



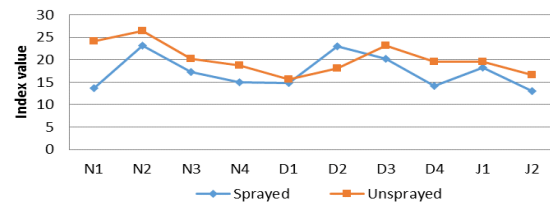
Family Level



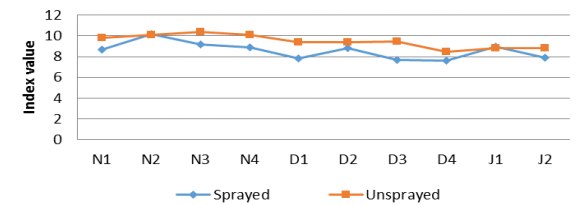
Family Level



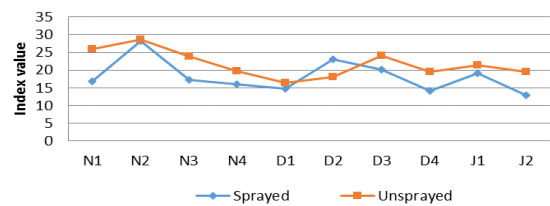
Generic Level



Generic Level



Species Level



Species Level

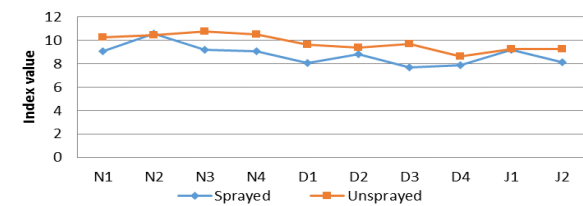


Fig 29. Arthropod diversity based on Shannon - Weiner index in tomato ecosystem

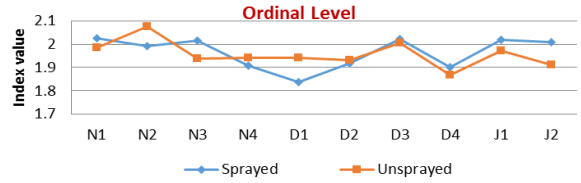
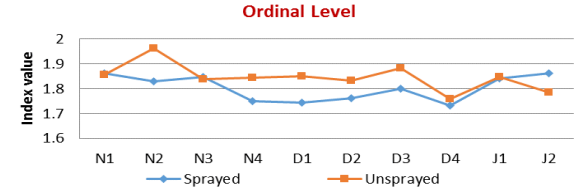
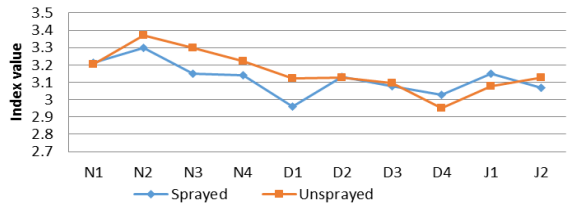


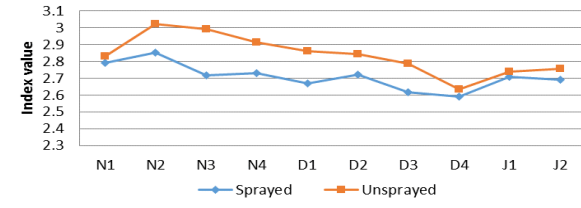
Fig 30. Arthropod diversity based on Brillouin diversity index in tomato ecosystem



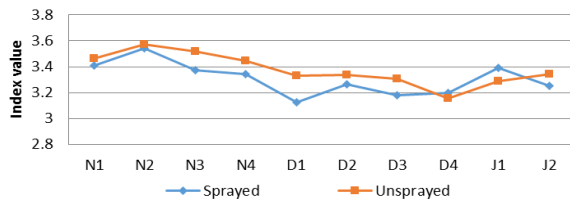
Family Level



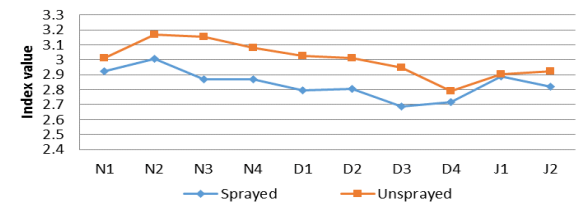
Family Level



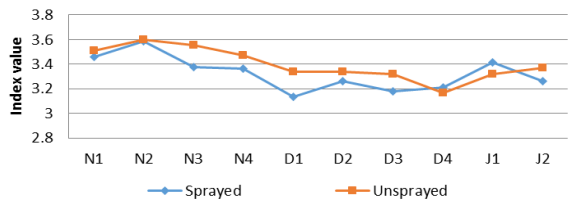
Generic Level



Generic Level



Species Level



Species Level

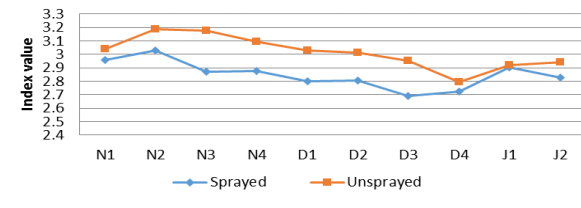
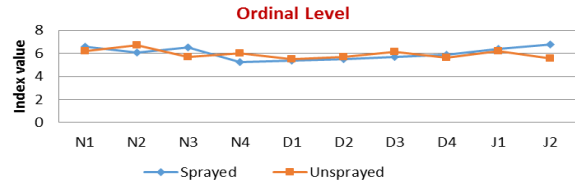
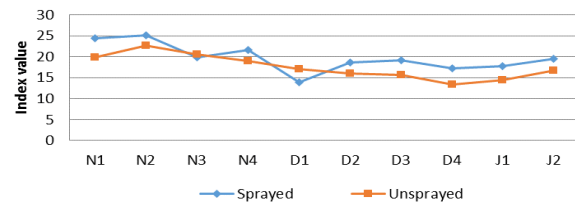


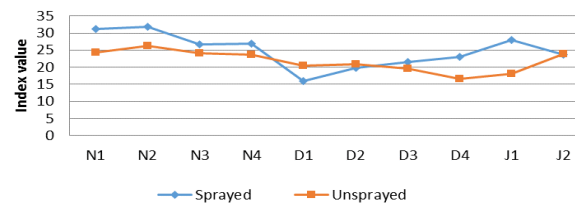
Fig 31. Arthropod diversity based on Simpson's index in tomato ecosystem



Family Level



Generic Level



Species Level

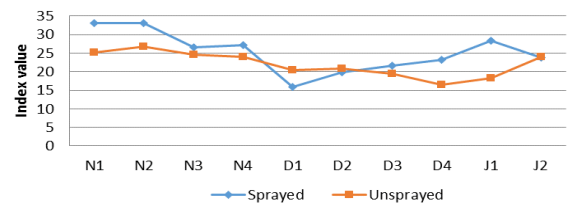
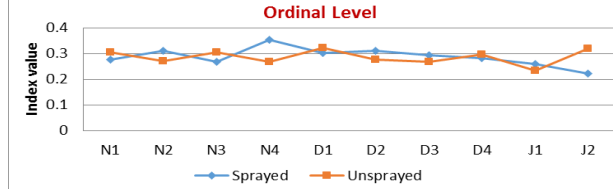
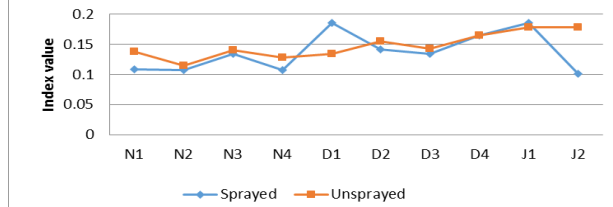


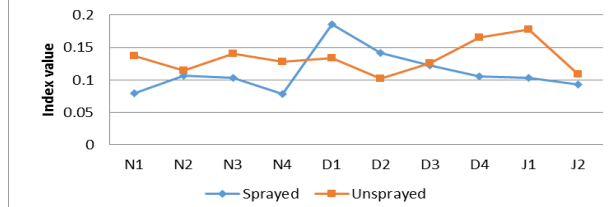
Fig 32. Arthropod diversity based on Berger Parker diversity in tomato ecosystem



Family Level



Generic Level



Species Level

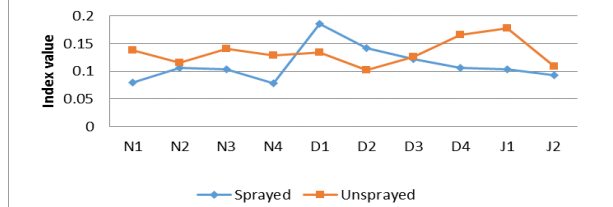


Fig 33. Arthropod diversity based on McIntosh index in tomato ecosystem

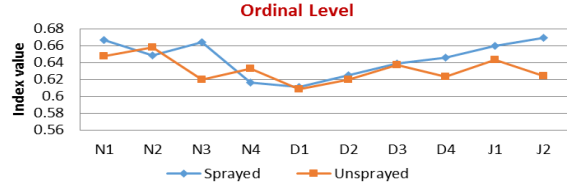
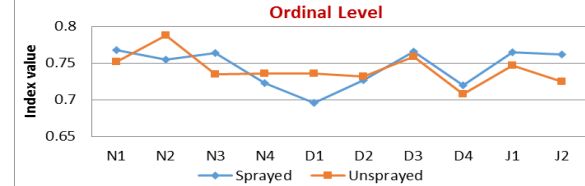
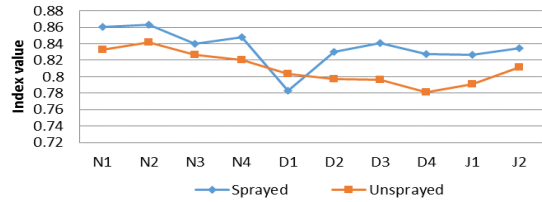


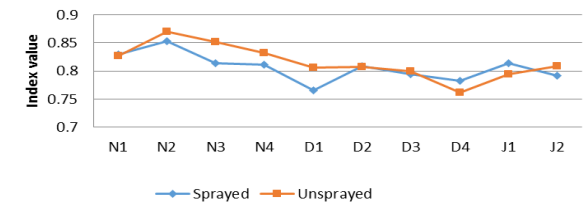
Fig 34. Arthropod diversity based on Evenness indices in tomato ecosystem



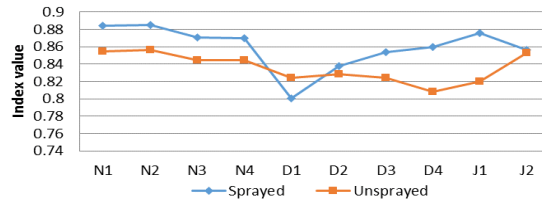
Family Level



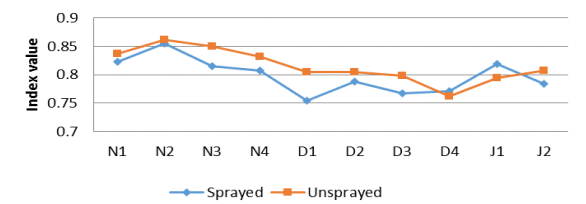
Family Level



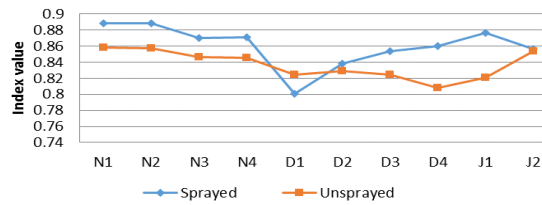
Generic Level



Generic Level



Species Level



Species Level

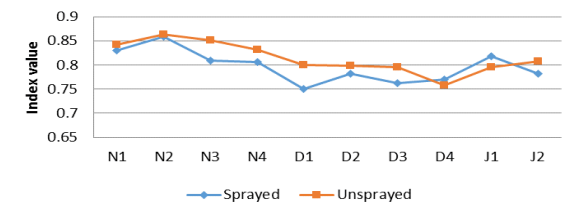


Fig 35. Arthropod diversity based on Beta diversity indices in tomato ecosystem

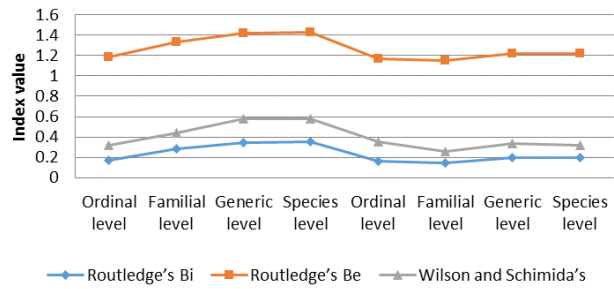
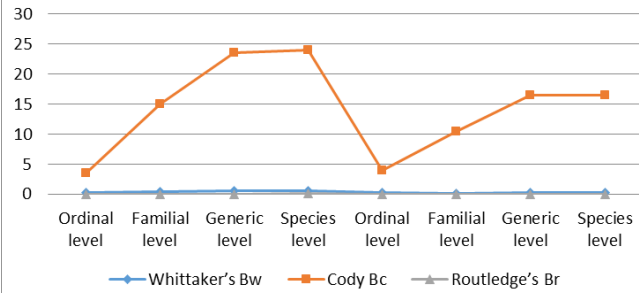
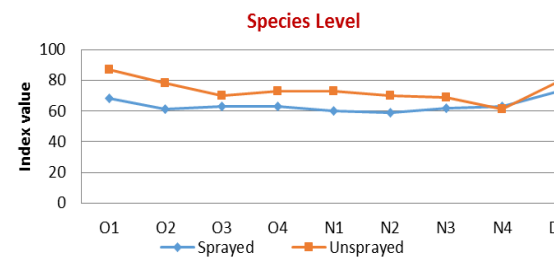
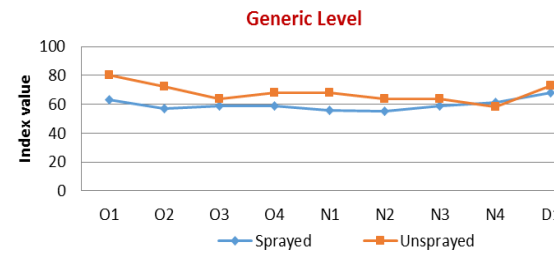
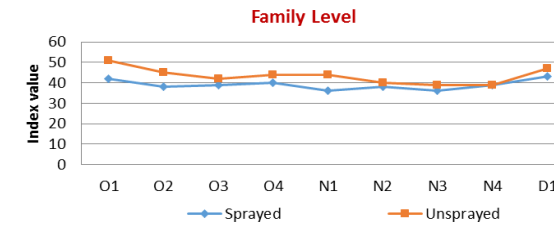
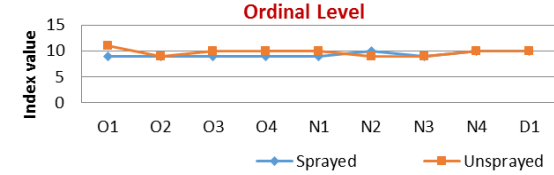


Fig.36 Arthropod diversity based on Species number in rice ecosystem



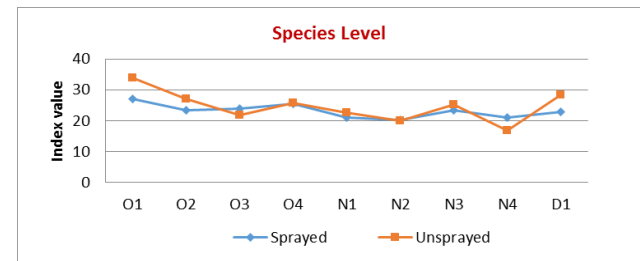
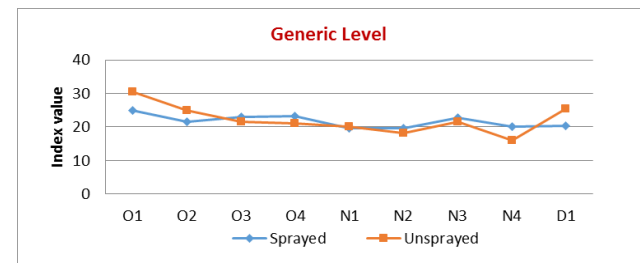
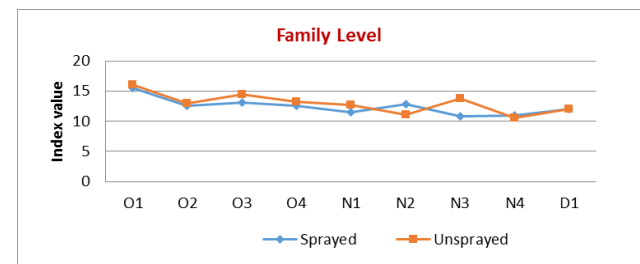
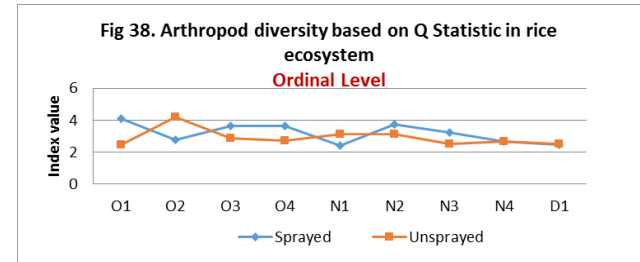
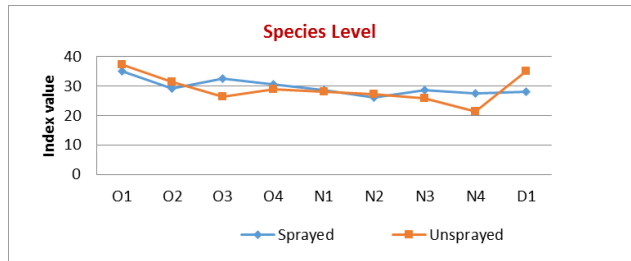
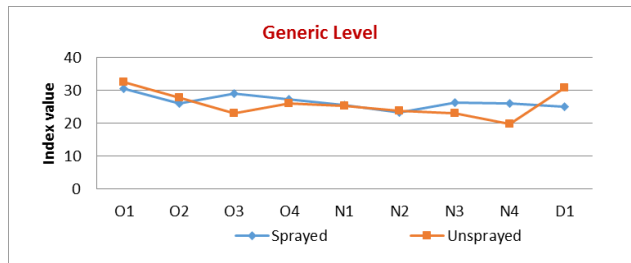
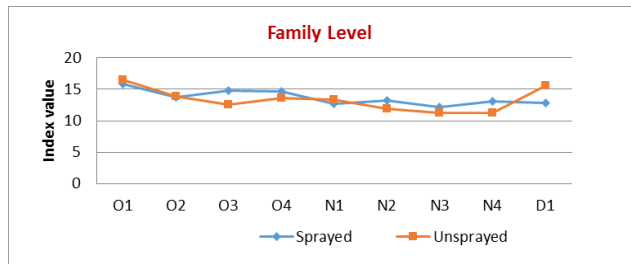
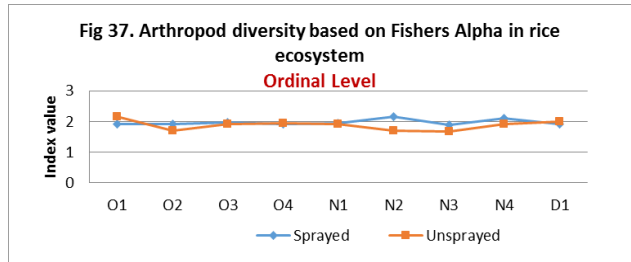
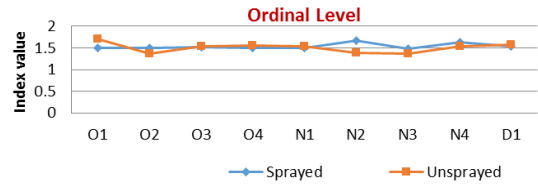
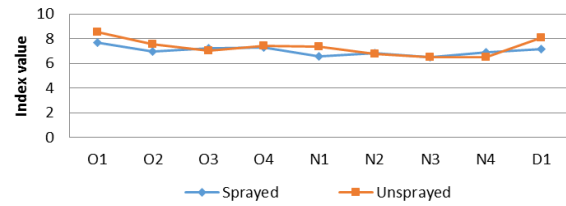


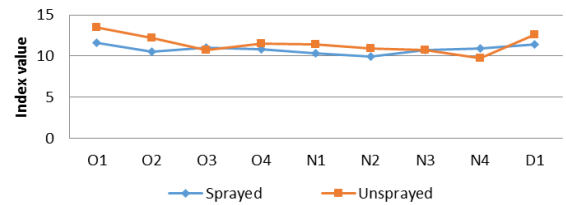
Fig 39. Arthropod diversity based on Margalef's D in rice ecosystem



Family Level



Generic Level



Species Level

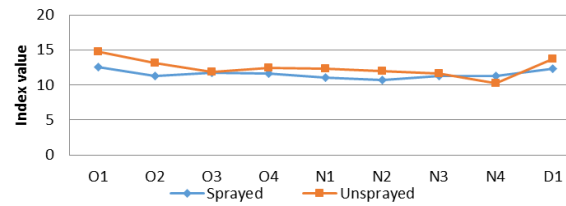
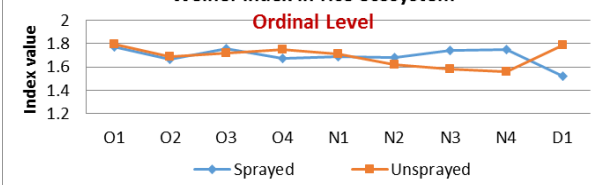
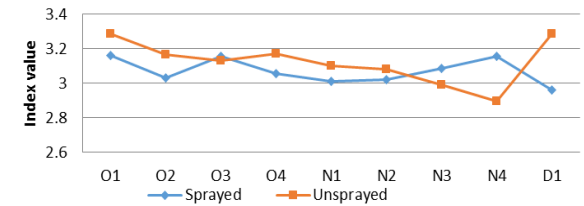


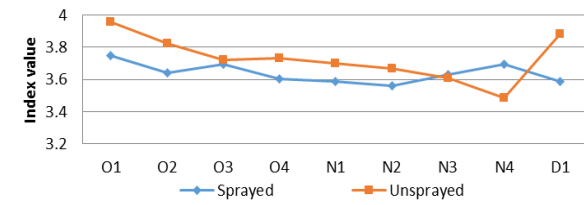
Fig 40. Arthropod diversity based on Shannon - Weiner index in rice ecosystem



Family Level



Generic Level



Species Level

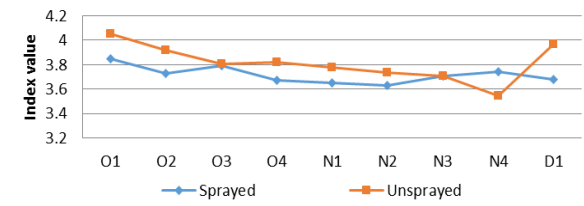
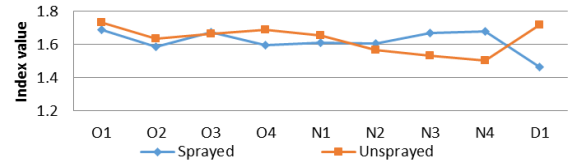
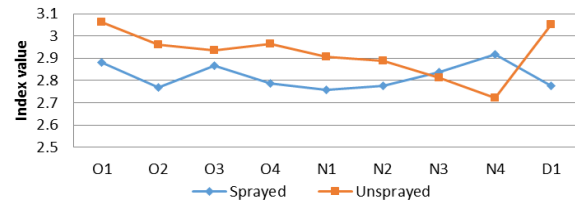


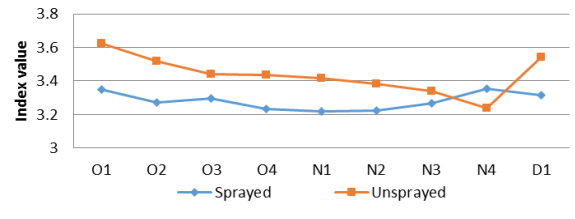
Fig 41. Arthropod diversity based on Brillouin diversity index in rice ecosystem
Ordinal Level



Family Level



Generic Level



Species Level

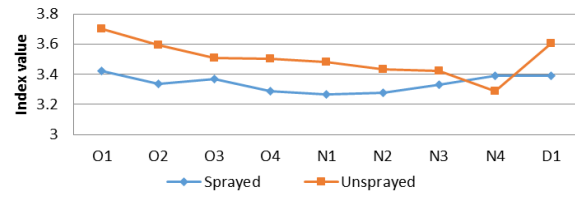
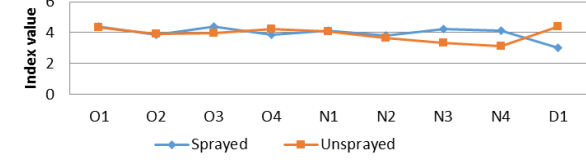
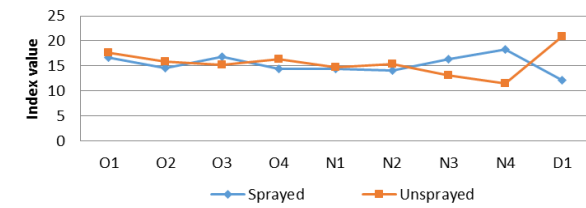


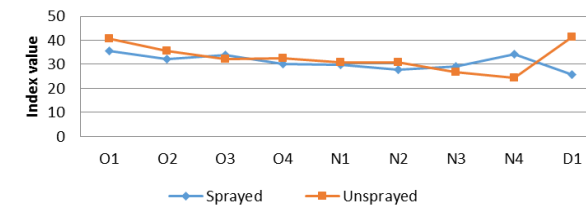
Fig 42. Arthropod diversity based on Simpson's index in rice ecosystem
Ordinal Level



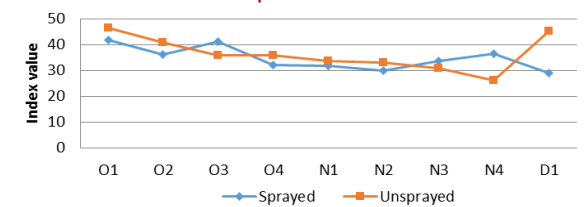
Family Level



Generic Level



Species Level



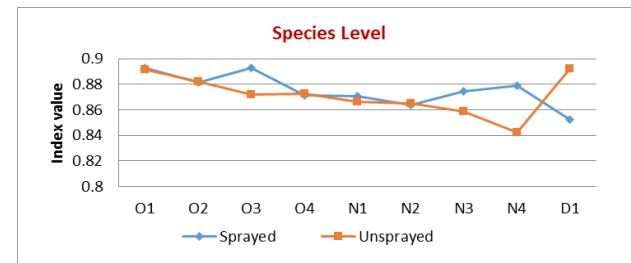
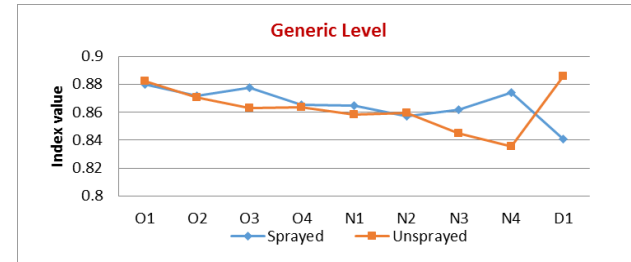
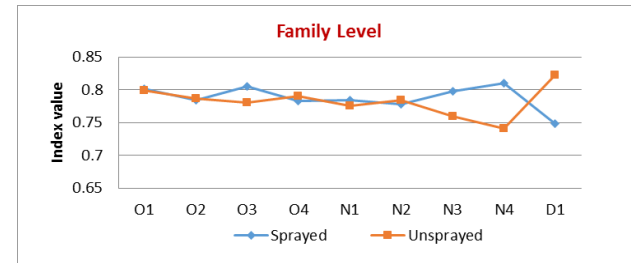
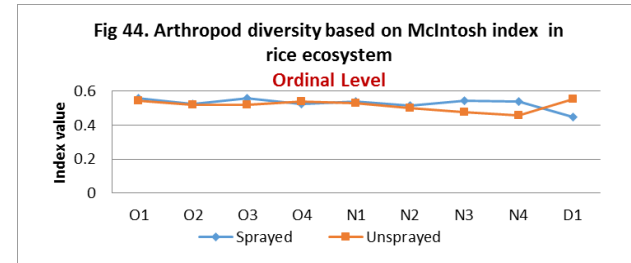
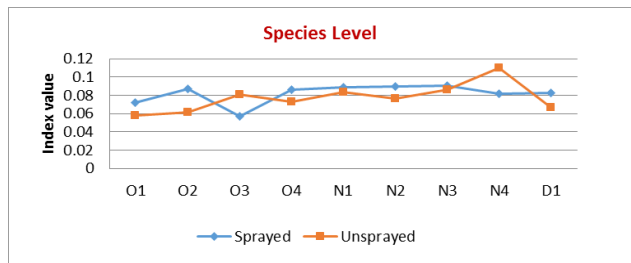
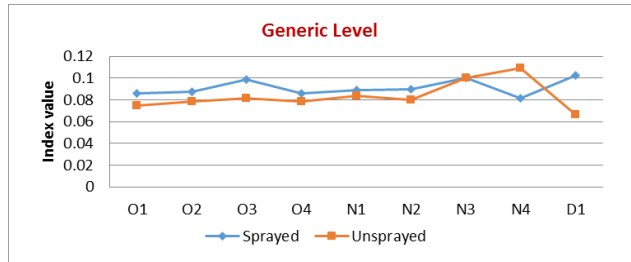
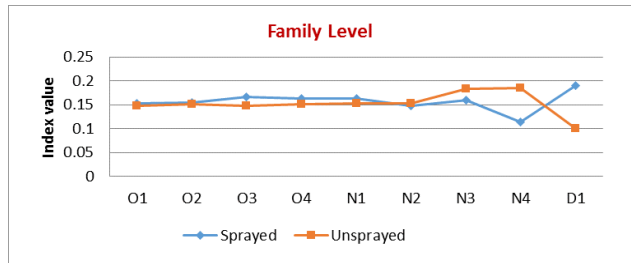
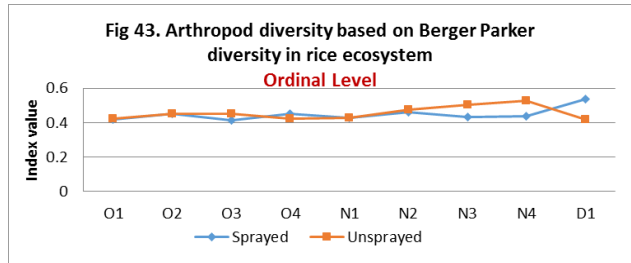
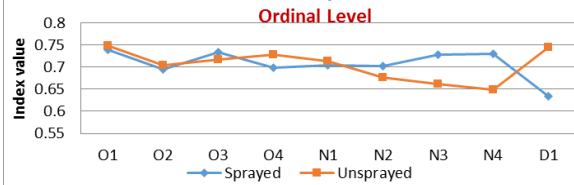
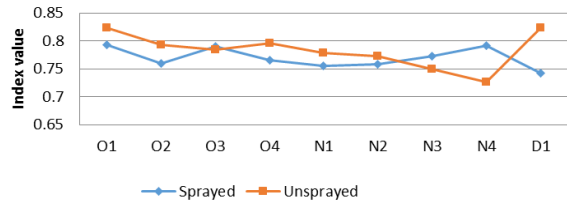


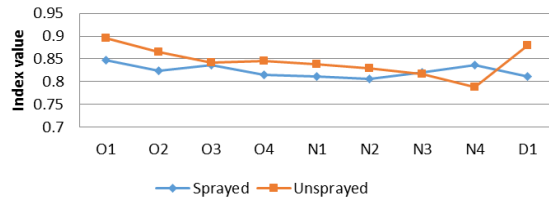
Fig 45. Arthropod diversity based on Evenness indices in rice ecosystem



Family Level



Generic Level



Species Level

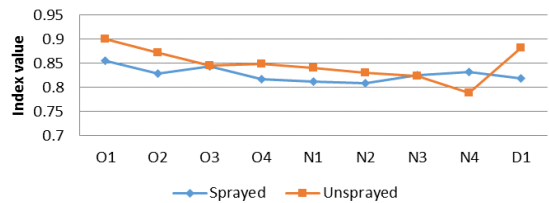
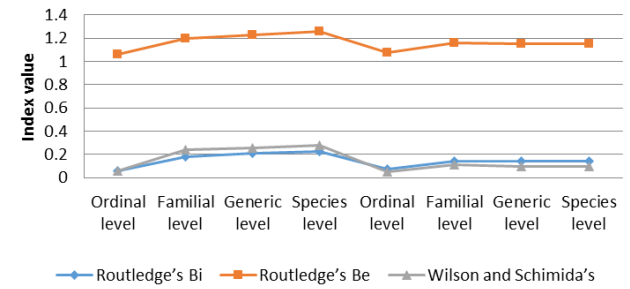
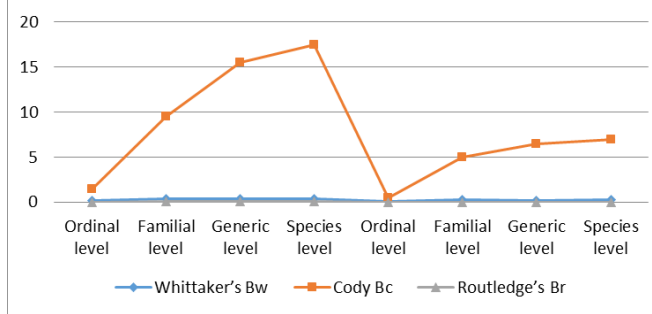
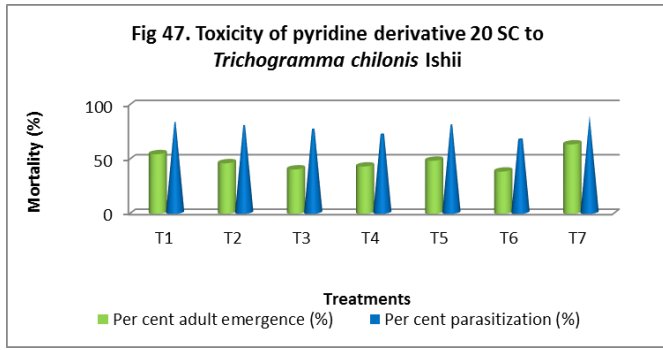
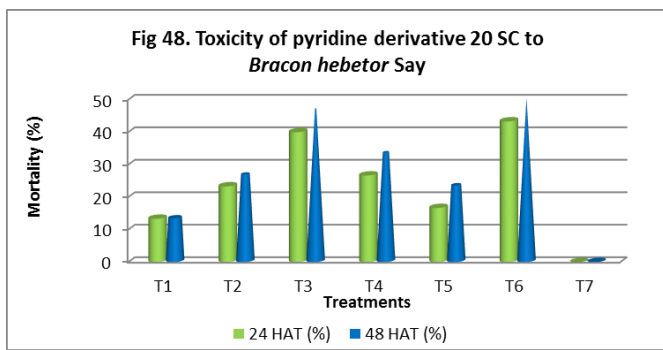


Fig 46. Arthropod diversity based on Beta diversity indices in rice ecosystem

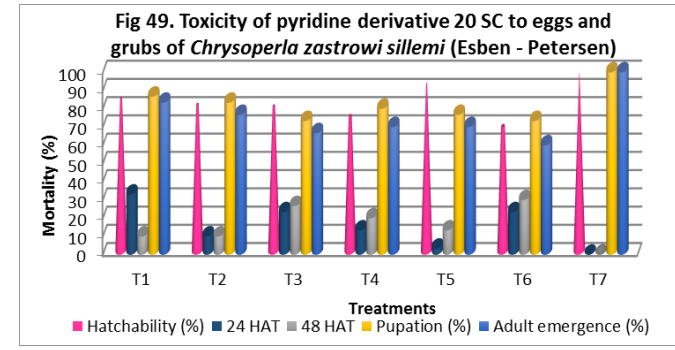




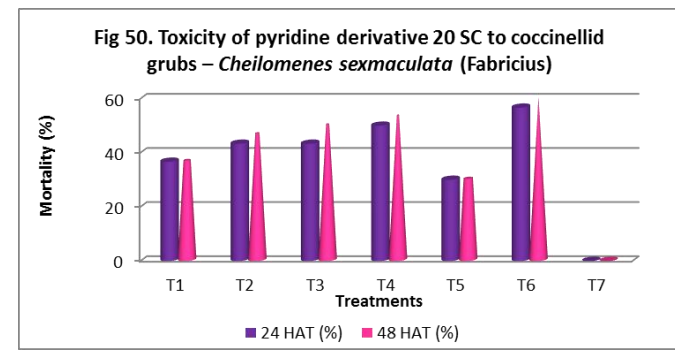
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check



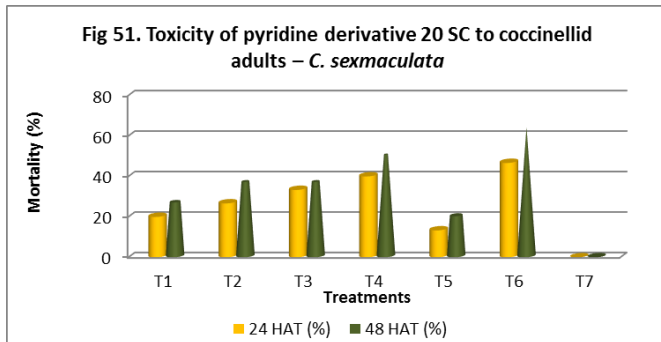
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 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check



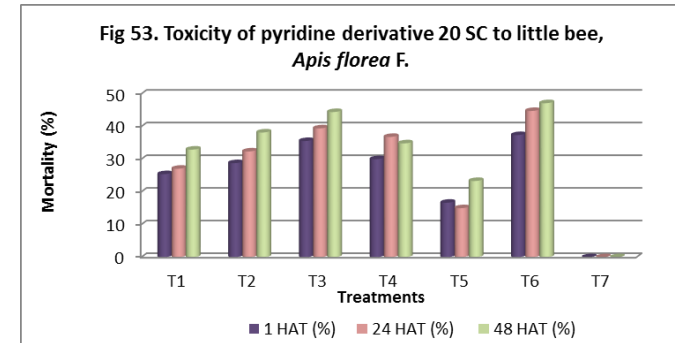
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check



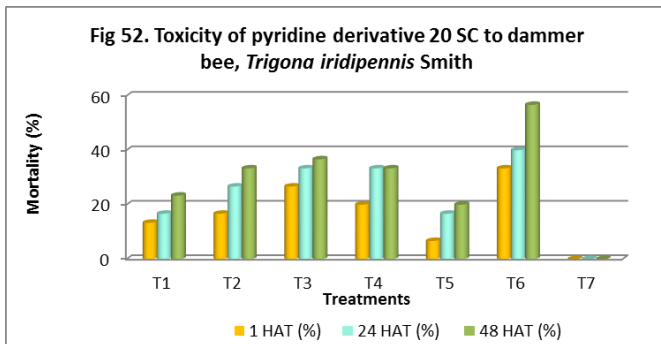
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check



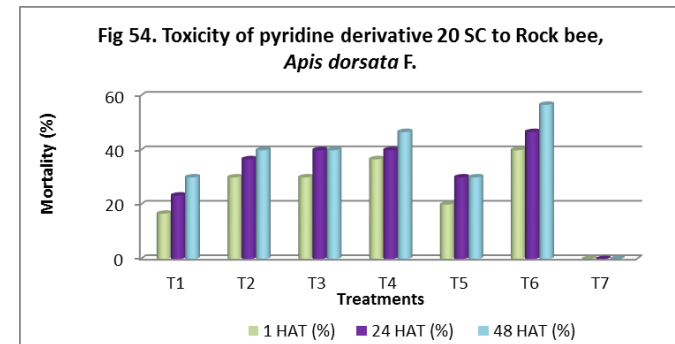
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check



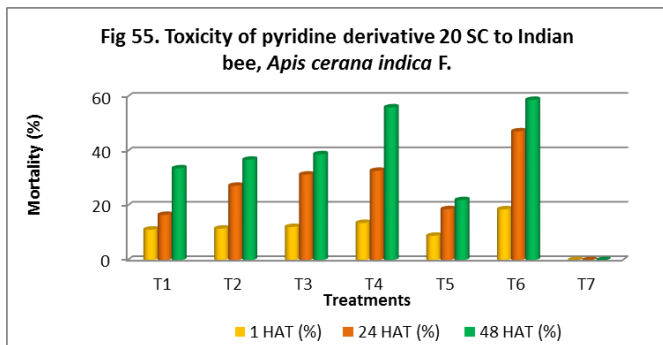
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check



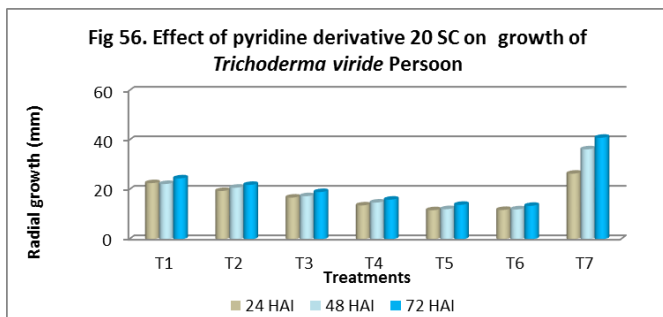
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check



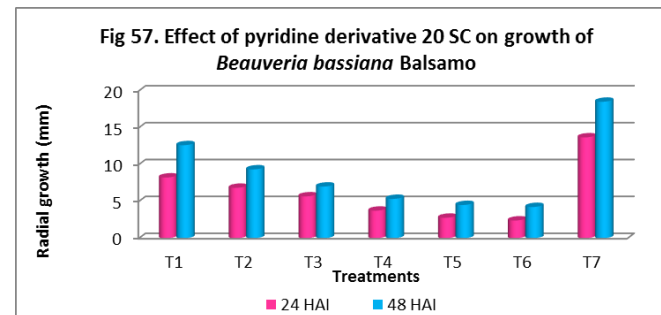
T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check



- T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check



- T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check



- T1 – Pyridine derivative SC 40 g a.i. ha⁻¹ T2 - Pyridine derivative SC 50 g a.i. ha⁻¹
 T3 - Pyridine derivative SC 60 g a.i. ha⁻¹ T4 – Chlorantraniliprole 20 SC 30 g a.i. ha⁻¹
 T5 – Novaluron10 EC 75 g a.i. ha⁻¹ T6 – Bifenthrin10 EC 50 g a.i. ha⁻¹
 T7- Untreated check

Fig. 58 Pairwise sequence alignment of transmembrane region of *Drosophila melanogaster* Meigen and *H. armigera*

```
# Length: 589
# Identity: 412/589 (69.9%)
# Similarity: 473/589 (80.3%)
# Gaps: 28/589 ( 4.8%)
# Score: 2090.0
#
#
#=====
Drosophila_TM      1 LIVGFFKIIFYIFYYTGYAHFCVVRVYIFGILLNLMRGPAPQEPEPVVEE      50
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
AHB33498.1        1 LAVGFFKMFYFYLYYLVVVRVYIFGVLGLMRGPQTEPPPEPTTE           50
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      51 ETFG-----RALLPLEEPPGTIVQ--AFGLDINKEENGMVKV           86
|.|. | | | | | | | | | | | | | | | | | | | | | | | | | | | |
AHB33498.1        51 EKIGQLRHRLLATQSSRHLPALPPADDTGQMQVSAFGLDITKEDNGIQV      100
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      87 VVHESPANSSMEEGESSPEDGAAASGELVEGEPHQEPIISIVDLLGGEAA     136
.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
AHB33498.1        101 KPHESPSTST----PSSGEEAEVSPDESIDHTEQRPPSLIDLGLGGEQA     145
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      137 KKAQERQEAQKAQEAAMASIEAEAKKSSAPQETPAVHQIDFSQYTHRA      186
|. | | | | | | | | | | | | | | | | | | | | | | | | | | | |
AHB33498.1        146 KKQAQERMEAQAQAAMSAIEAEAKKAVQGPAPS-ALSQVDSLQYTRRA     194
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      187 VSFLARNFYNLKYVALVLAFLAFINMFLFYKVTSF-TEEADSSAEELILG     235
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
AHB33498.1        195 VSFLARNFYNLKYVALVLAFCINFVLLFYKVTSLDAEGGEGSGLDGIAC     244
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      236 SGGGGADITGSGFGGSGDGGSDGEMEDELPELVHVEDFFYMEHVLRI      285
|. | | | | | | | | | | | | | | | | | | | | | | | | | | | |
AHB33498.1        245 GSGSGGA---GS---GSGDGGSGESGEDDDALEVHVIDEDFFYMEHVIMK     288
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      286 AACLHSLVSLAMLIAYYHLKVLPLAIFKREKEIARRLEFEGLFIAEQPEDD     335
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
AHB33498.1        289 AAVLHSIVSLAIIIGYYHLKVLPLAIFKREKEIARKLEFDGLYIAEQPEDD     338
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      336 DFKSHWDKLVISAKSFPVNYWDFVKKKVRQKYSETYDFDISNLLGMEK      385
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
AHB33498.1        339 DLKSHWDKLVISAKSFPVNYWDFVKKKVRQKYSETYDFDISNLLGMEK      388
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      386 STFAAQESE-ETGIFKYIMNIDWRYQVWKAGVTFDINAFLYSLWYFSPV      434
.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
AHB33498.1        389 TSFSAQEEEGSKGLIHYLIINIDWRYQVWKAGVITIDNSFLYSLWYFSPV     438
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      435 MGNFMNFFFAAHLLDVAVGFKTLRITLQSVTHNGKQLVLTVMLLTIIVYI     484
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
AHB33498.1        439 MGNFMNFFFAAHLLDVAVGFKTLRITLQSVTHNGKQLVLTVMLLTIIVYI     488
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      485 YTVIAFNFFFRKFYIQEEDDEVKCKHDMLTCTFVFLYKGVRAAGGGIGDEI     534
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
AHB33498.1        489 YTVIAFNFFFRKFYIQEEDDEVNRMCHDMLTCTFVFLYKGVRAAGGGIGDEL     538
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      535 GPDGDDYEVYRIIFDITFFVFVIIILLAIQGLIIDAF           573
.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
AHB33498.1        539 EPPDGDDEYVYRIIFDISFFVFVIIILLAIQGLIIDAF           577
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
```

Fig. 59 Pairwise sequence alignment of transmembrane region of *D. melanogaster* and *Apis mellifera* Linnaeus

```
#
# Length: 590
# Identity: 406/590 (68.8%)
# Similarity: 466/590 (79.0%)
# Gaps: 24/590 ( 4.1%)
# Score: 2041.0
#
#
#=====
Drosophila_TM      1 LIVGFFKIIFYIFYYTGYAHFCVVRVYIFGILLNLMRGPAPQEPEPVV--     48
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    1 LFIQFFKMFYFYLYYLVVVRVYIFGVLGLMRGPQTEPPPEPTTE           47
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      49 --EETFGR---ALPPLPLEEPPGTIVQAFGLDINKEENGMVKVHVHESPA     93
| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
XP_006569093.    48 KEEEEKPSRHLPALPPTP-DESNLQVQAFGMDITKEEGGQIKIAPHESAT     96
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      94 N---SSMEEGESSPEDGAAASGELVEGEPHQEPIISIVDLLGGEAAKKA     139
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    97 STPQSSIEETGESTPEEATGEEASARAEAGGDMESPVSLADLLGGEQARAQ     146
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      140 AQERQEAQKAQEAAMASIEAEAKKSSAPQETPAVHQIDFSQYTHRAVSF     189
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    147 AAAAAEAAAQAAMAAVEAEAKQETIA--EPSASSIDFSEYTHRVVSF         193
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      190 LARNFYNLKYVALVLAFLAFINMFLFYKVTSFTEEADSSAEELI--LGSG     237
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    194 LARNFYNLKYVALVLAFCINFVLLFYKVTSLDSEGGEGSGQIVDNLAEI     243
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      238 SGGGADITGSGFG---GSGDGGSGDGEDEIP-ELVHVEDFFYMEHVL      283
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    244 SGEASGSGNGSGWEIGSGSGEAESEEEDEVALEYVEVAEDFFYMAHVI     293
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      284 RIAACLHSLVSLAMLIAYYHLKVLPLAIFKREKEIARRLEFEGLFIAEQPE     333
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    294 RLMAILHAIVSLAMLVAYYHLKVLPLAIFKREKEIARRVEFDGLYIAETPE     343
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      334 DDDFKSHWDKLVISAKSFPVNYWDFVKKKVRQKYSETYDFDISNLLGMEK     383
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    344 EDDIKAHWDKLVISAKTFFVNYWDFVKKKVRQKYSETYDFDISNLLGMEK     393
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      384 EKSTFAAQESEETGIFKYIMNIDWRYQVWKAGVTFDINAFLYSLWYFSPV     433
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    394 EKTSTFSAQEEEGSKGLIHYLIINIDWRYQVWKAGVITIDNAFLYSLWYFSPV     443
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      434 VMGNFMNFFFAAHLLDVAVGFKTLRITLQSVTHNGKQLVLTVMLLTIIVY     483
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    444 ILGNFMNFFFAAHLLDVAVGFKTLRITLQSVTHNGKQLVLTVMLLTIIVY     493
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      484 IYTVIAFNFFFRKFYIQEEDDEVKCKHDMLTCTFVFLYKGVRAAGGGIGDE     533
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    494 IYTVIAFNFFFRKFYIQEEDDEVKCKHDMLTCTFVFLYKGVRAAGGGIGDE     543
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|

Drosophila_TM      534 IGDGDDYEVYRIIFDITFFVFVIIILLAIQGLIIDAF           573
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
XP_006569093.    544 IGDGDDYEVYRIIFDITFFVFVIIILLAIQGLIIDAF           583
|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|.:|
```

Fig. 60 Pairwise sequence alignment of transmembrane region of *D. melanogaster* and *Tribolium castaneum* (Herbst)

```

#
# Length: 585
# Identity: 414/585 (70.8%)
# Similarity: 470/585 (80.3%)
# Gaps: 32/585 ( 5.5%)
# Score: 2073.0
#
#
#-----
Drosophila_TM 1 LIVGFFKIIIFYFYTYGVAHFCVVRVYIFGILLNLMRGPAPQEIEPVV-- 48
AIU40166.1 1 LFIGFFKMIIFYFYTYGVAHFCVVRVYIFGILLNLMRGPAPI----EPAVLE 46
Drosophila_TM 49 ---EETFG--RALPPLPLEEPPGT-VQAFGLDINKEENGMKYVVVHESP 92
AIU40166.1 47 KEKEEKVGLSRVLPALPSSEEQNTQMQAFGLDITKEDNGQYKMAAESHP 96
Drosophila_TM 93 AN--SSMEEGESSPEDGAAASGELVEGEPHQEPISIVDLLGEEAAKKA 139
AIU40166.1 97 TTSQPSAAEGEGETTPEE---DGEHPETETMEAPLSLSDLLGEGQAKRA 142
Drosophila_TM 140 AQERQEAQAQEAAMASIEAEAKKSSAPQETPAVHQIDFSQYTHRAVSF 189
AIU40166.1 143 AQEKVEAQAQAQAVNQAIESESKQ--PVTPEPSAVSQINFGAYSHRAVSF 190
Drosophila_TM 190 LARNFYNLKYVALVLAFCINFMFLFYKVTSTFEADSSAEELILGSGSG 239
AIU40166.1 191 LARNFYNLKYVALVLAFCINFMFLFYRVSTLGDADAE-----GSGSK 231
Drosophila_TM 240 GGADITGSGFGSGDGGSGDGEDEIPELVHVDDEFFYMEHVLRIAAACL 289
AIU40166.1 232 GIPDILEGSAEGSG-AGSGESGEDDDPELVHVDDEFFYMAHVRLAAAL 280
Drosophila_TM 290 HSLVSLAMLIAYYHLKVP LAIFKREKEIARRLEFGLTAEQPEDDDFKS 339
AIU40166.1 281 HSVVSLAMLIAYYHLKVP LAIFKREKEIARRLEFGLYIAEQPEDDGLKS 330
Drosophila_TM 340 HWDKLVISAKSFPVNYWDFVKKVQRQKYSETYDFDSISNLLGMEKSTFA 389
AIU40166.1 331 HWDKLVISAKSFPVNYWDFVKKVQRQKYSETYDFDSISNLLGMEKTSFQ 380
Drosophila_TM 390 AQESEETGIFKY-IMNIDWRYQVWKAGVTFDQNAFLYSLWYFVSVMGNF 438
AIU40166.1 381 QQESDEGRSFIYFIINIDWRYQVWKAGVTFDQNAFLYSLWYFVSILGNF 430
Drosophila_TM 439 NNFFFAAHLDDVAVGFKTLRRTLQSVTHNGKQLVLTVMLLTIVVIYTVI 488
AIU40166.1 431 NNFFFAAHLDDVAVGFKTLRRTLQSVTHNGQLVLTVMLLTIVVIYTVI 480
Drosophila_TM 489 AFNFFRKYIQQEEDVDDKCHDMLTCFVPHLYKGVRRAGGGIGDEIGDPD 538
AIU40166.1 481 AFNFFRKYIQQEEDVDDKCHDMLTCFVPHLYKGVRRAGGGIGDEIEPPD 530
Drosophila_TM 539 GDDYEVYRIIFDITFFFVVIILLAIQGLIIDAF 573
AIU40166.1 531 GDDYEVYRIMFDITFFFVVIILLAIQGLIIDAF 565

```

Fig. 61 Pairwise sequence alignment of transmembrane region of *D. melanogaster* and *Bactrocera cucurbitae* (Coquillett)

```

#
# Length: 584
# Identity: 500/584 (85.6%)
# Similarity: 535/584 (91.6%)
# Gaps: 17/584 ( 2.9%)
# Score: 2566.0
#
#
#-----
Drosophila_TM 1 LIVGFFKIIIFYFYTYGVAHFCVVRVYIFGILLNLMRGPAPQEIEPVVVE 50
XP_011193744.1 1 LIIGFFKMIIFYFYTYGVAHFCVVRVYIFGILLNLMRGPAPQEIEAPVVE 50
Drosophila_TM 51 ETFGRALPPLPLEEPPGTVQAFGLDINKEENGMKYVVVHESP---ANSSM 97
XP_011193744.1 51 ETFGKMLPPLPIEPPGTVQAFGLDINKEENGMKYVVVHESP---ANSSM 100
Drosophila_TM 98 EEGESSPEDGAAASGELVEGEPHQEPISIVDLLGEEAAKKAQERQE 145
XP_011193744.1 101 EETGESSPEEGGTTADQAIESEQYQLQEPISIVDLLGEEAAKKAQERQE 150
Drosophila_TM 146 AQKAQEAAMASIEAEAKKSSA-POETPAVHQIDFSQYTHRAVSFLARNF 194
XP_011193744.1 151 AQKAQEAAMASIEAEAKKSSATAQETPAVHQIDFAQYHRAVSFLARNF 200
Drosophila_TM 195 YNLKYVALVLAFCINFMFLFYKVTSTFEADSSAEELILGSGSGGGADI 244
XP_011193744.1 201 YNLKYVALVLAFCINFMFLFYKVTSTFGDDEASGDELILGSGS--GSSL 248
Drosophila_TM 245 TGSFGG-----SGDGGSGDGEDEIPELVHVDDEFFYMEHVLRIAAACL 289
XP_011193744.1 249 SASGFGGSGDSSGCGG-GD---EEDLPELVHVDDEFFYMAHVRLAAAL 294
Drosophila_TM 290 HSLVSLAMLIAYYHLKVP LAIFKREKEIARRLEFGLTAEQPEDDDFKS 339
XP_011193744.1 295 HSLVSLAMLIAYYHLKVP LAIFKREKEIARRLEFDGLFIADQPEDDDFKS 344
Drosophila_TM 340 HWDKLVISAKSFPVNYWDFVKKVQRQKYSETYDFDSISNLLGMEKSTFA 389
XP_011193744.1 345 HWDKLVISAKSFPVNYWDFVKKVQRQKYSETYDFDSISNLLGMEKSAFM 394
Drosophila_TM 390 AQESEETGIFKYIMNIDWRYQVWKAGVTFDQNAFLYSLWYFVSVMGNF 439
XP_011193744.1 395 AQESEEGGLIKYIMNIDWRYQVWKAGVTFDQNAFLYSLWYFVSVMGNF 444
Drosophila_TM 440 NFFFAAHLDDVAVGFKTLRRTLQSVTHNGKQLVLTVMLLTIVVIYTVIA 489
XP_011193744.1 445 NFFFAAHLDDVAVGFKTLRRTLQSVTHNGKQLVLTVMLLTIVVIYTVIA 494
Drosophila_TM 490 FNFFRKYIQQEEDVDDKCHDMLTCFVPHLYKGVRRAGGGIGDEIGDPDG 539
XP_011193744.1 495 FNFFRKYIQQEEDVDDKCHDMLTCFVPHLYKGVRRAGGGIGDEIGDPDG 544
Drosophila_TM 540 DDYEVYRIIFDITFFFVVIILLAIQGLIIDAF 573
XP_011193744.1 545 DDYEVYRIIFDITFFFVVIILLAIQGLIIDAF 578

```


Fig. 64 Phylogenetic analysis of the ryanodine receptor (RyR) in different insect species.

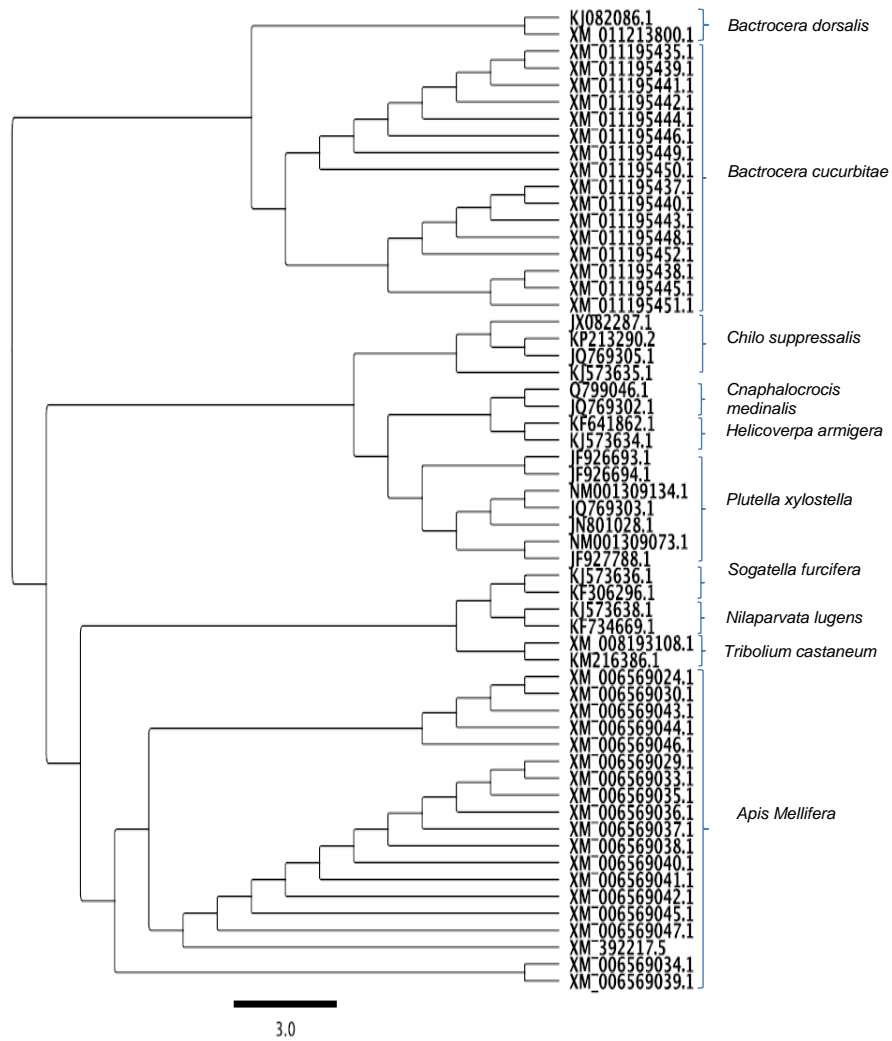


Table 62. Toxicity of pyridine derivative 20 SC to *Trichogramma chilonis* Ishii

Treatment	Dose (g a.i. ha ⁻¹)	Adult emergence* (%)	Parasitization* (%)
Pyridine derivative 20 SC	40	55.00 (47.88) ^b	82.67 (65.40) ^b
Pyridine derivative 20 SC	50	46.67 (43.09) ^{cd}	79.67 (63.20) ^c
Pyridine derivative 20 SC	60	41.00 (39.78) ^{de}	76.33 (60.89) ^d
Chlorantranilprole 20 SC	30	43.67 (41.36) ^{cde}	71.67 (57.84) ^e
Novaluron 10 EC	75	49.00 (44.43) ^{bc}	80.33 (63.68) ^c
Bifenthrin 10 EC	50	39.00 (38.64) ^e	67.00 (54.94) ^f
Untreated control	-	64.00 (53.15) ^a	88.67 (70.33) ^a

*Mean of three replications; In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT
 Figures in parentheses are arcsine $\sqrt{\text{Per cent transformed values}}$

Table 63. Toxicity of pyridine derivative 20 SC to *Bracon hebetor* Say

Treatment	Dose (g a.i. ha ⁻¹)	24 HAT		48 HAT	
		Mortality* (%)	Corrected mortality	Mortality* (%)	Corrected mortality
Pyridine derivative 20 SC	40	16.67 (23.86) ^b	13.33	23.33 (28.78) ^b	13.33
Pyridine derivative 20 SC	50	26.67 (31.00) ^b	23.33	36.67 (37.22) ^c	26.67
Pyridine derivative 20 SC	60	43.33 (41.15) ^{cd}	40.00	56.67 (48.85) ^d	46.67
Chlorantranilprole 20 SC	30	30.00 (33.21) ^{bc}	26.67	43.33 (41.15) ^c	33.33
Novaluron 10 EC	75	20.00 (26.57) ^b	16.67	33.33 (35.22) ^{bc}	23.33
Bifenthrin 10 EC	50	46.67 (43.08) ^d	43.33	60.00 (50.85) ^d	50.00
Untreated control	-	3.33 (6.14) ^a	0.00	10.00 (18.43) ^a	0.00

*Mean of three replications; HAT - Hour after treatment

In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT

Figures in parentheses are arcsine $\sqrt{\text{Per cent}}$ transformed values

Table 64. Toxicity of pyridine derivative 20 SC to the eggs of *Chrysoperla zastrowi sillemi* (Esben - Petersen)

Treatment	Dose (g a.i. ha ⁻¹)	Egg Hatchability* (%)
Pyridine derivative 20 SC	40	83.22 (66.17) ^{bc}
Pyridine derivative 20 SC	50	79.91 (63.64) ^{bc}
Pyridine derivative 20 SC	60	79.05 (62.97) ^{bc}
Chlorantranilprole 20 SC	30	73.64 (59.20) ^c
Novaluron 10 EC	75	91.17 (72.77) ^{ab}
Bifenthrin 10 EC	50	68.05 (55.76) ^c
Untreated control	-	96.49 (83.69) ^a

*Mean of three replications

In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT

Figures in parentheses are arcsine $\sqrt{\text{Per cent}}$ transformed values

Table 65. Toxicity of pyridine derivative 20 SC to the grubs of *C. zastrowi sillemi*

Treatment	Dose (g a.i. ha ⁻¹)	Mortality* (%)		Pupation* (%)	Adult emergence* (%)
		24 HAT	48 HAT		
Pyridine derivative 20 SC	40	3.33 (6.14) ^{ab}	10.00 (15.00) ^b	86.67 (68.86) ^b	83.33 (66.64) ^b
Pyridine derivative 20 SC	50	10.00 (15.00) ^{abc}	10.00 (15.00) ^b	83.33 (66.64) ^{bc}	76.67 (61.22) ^{bc}
Pyridine derivative 20 SC	60	23.33 (28.78) ^c	26.67 (31.00) ^{cd}	73.33 (59.00) ^c	66.67 (54.78) ^{cd}
Chlorantraniliprole 20 SC	30	13.33 (21.14) ^{bc}	20.00 (26.57) ^{cd}	80.00 (63.43) ^{bc}	70.00 (57.00) ^{cd}
Novaluron 10 EC	75	3.33 (6.14) ^{ab}	13.33 (21.14) ^b	76.67 (61.22) ^c	70.00 (57.00) ^{cd}
Bifenthrin 10 EC	50	23.33 (28.78) ^c	30.00 (33.21) ^d	73.33 (59.00) ^c	60.00 (50.85) ^d
Untreated control	-	0.00 (0.00) ^a	0.00 (0.00) ^a	100.00 (90.00) ^a	100.00 (90.00) ^a

*Mean of three replications; HAT - Hour after treatment

In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT

Figures in parentheses are arcsine $\sqrt{\text{Per cent}}$ transformed values

Table 66. Toxicity of pyridine derivative 20 SC to coccinellid grubs – *Cheilomenes sexmaculata* (Fabricius)

Treatment	Dose (g a.i. ha ⁻¹)	24 HAT		48 HAT	
		Grubs Mortality* (%)	Corrected mortality	Grubs Mortality* (%)	Corrected mortality
Pyridine derivative 20 SC	40	43.33 (41.15) ^{bc}	36.67	53.33 (46.92) ^b	36.67
Pyridine derivative 20 SC	50	50.00 (45.00) ^{bcd}	43.33	63.33 (52.78) ^c	46.67
Pyridine derivative 20 SC	60	50.00 (45.00) ^{bcd}	43.33	66.67 (54.78) ^c	50.00
Chlorantraniliprole 20 SC	30	56.67 (48.85) ^{cd}	50.00	70.00 (56.79) ^{cd}	53.33
Novaluron 10 EC	75	36.67 (37.22) ^b	30.00	46.67 (43.08) ^b	30.00
Bifenthrin 10 EC	50	63.33 (52.78) ^d	56.67	76.67 (61.22) ^d	60.00
Untreated control	-	6.67 (12.29) ^a	0.00	16.67 (23.86) ^a	0.00

*Mean of three replications; HAT - Hour after treatment

In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT

Figures in parentheses are arcsine $\sqrt{\text{Per cent}}$ transformed values

Table 67. Toxicity of pyridine derivative 20 SC to coccinellid adults – *C. sexmaculata*

Treatment	Dose (g a.i. ha ⁻¹)	24 HAT		48 HAT	
		Mortality* (%)	Corrected mortality	Mortality* (%)	Corrected mortality
Pyridine derivative 20 SC	40	23.33 (28.78) ^{bc}	20.00	33.33 (35.22) ^{bc}	26.67
Pyridine derivative 20 SC	50	30.00 (33.21) ^{cd}	26.67	43.33 (41.15) ^{cd}	36.67
Pyridine derivative 20 SC	60	36.67 (37.22) ^d	33.33	43.33 (41.15) ^{cd}	36.67
Chlorantraniliprole 20 SC	30	43.33 (41.15) ^{de}	40.00	56.67 (48.85) ^{de}	50.00
Novaluron 10 EC	75	16.67 (23.86) ^b	13.33	26.67 (31.00) ^b	20.00
Bifenthrin 10 EC	50	50.00 (45.00) ^e	46.67	70.00 (56.79) ^e	63.33
Untreated control	-	3.33 (6.14) ^a	0.00	6.67 (12.29) ^a	0.00

*Mean of three replications; HAT - Hour after treatment

In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT

Figures in parentheses are arcsine $\sqrt{\text{Per cent transformed values}}$

Table 68. Toxicity of pyridine derivative 20 SC to dammer bee, *Trigona iridipennis* Smith

Treatment	Dose (g a.i. ha ⁻¹)	1HAT		12 HAT		24 HAT	
		Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality
Pyridine derivative 20 SC	40	16.67 (23.56) ^{bc}	13.33	20.00 (26.57) ^b	16.67	30.00 (33.21) ^{bc}	23.33
Pyridine derivative 20 SC	50	20.00 (26.57) ^{cd}	16.67	30.00 (33.21) ^{bc}	26.67	40.00 (39.23) ^c	33.33
Pyridine derivative 20 SC	60	30.00 (33.21) ^{de}	26.67	36.67 (37.22) ^c	33.33	43.33 (41.15) ^c	36.67
Chlorantraniliprole 20 SC	30	23.33 (28.78) ^{cd}	20.00	36.67 (37.22) ^c	33.33	40.00 (39.23) ^c	33.33
Novaluron 10 EC	75	10.00 (18.43) ^b	6.67	20.00 (26.57) ^b	16.67	26.67 (31.00) ^b	20.00
Bifenthrin 10 EC	50	36.67 (37.22) ^e	33.33	43.33 (41.15) ^c	40.00	63.33 (52.78) ^d	56.67
Untreated control	-	3.33 (6.14) ^a	0.00	3.33 (6.14) ^a	0.00	6.67 (12.29) ^a	0.00

*Mean of three replications; HAT – Hour after treatment

In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT

Figures in parentheses are arcsine $\sqrt{\text{Per cent transformed values}}$

Table 69. Toxicity of pyridine derivative 20 SC to little bee, *Apis florea* Fabricius

Treatment	Dose (g a.i. ha ⁻¹)	1HAT		12 HAT		24 HAT	
		Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality
Pyridine derivative 20 SC	40	28.75 (31.52) ^b	25.42	38.75 (38.34) ^{bc}	27.08	46.26 (42.86) ^{bc}	32.93
Pyridine derivative 20 SC	50	32.12 (34.48) ^b	28.79	44.04 (41.57) ^{cd}	32.37	51.52 (45.87) ^{cd}	38.18
Pyridine derivative 20 SC	60	38.89 (38.22) ^b	35.56	51.11 (45.64) ^{cd}	39.44	57.78 (49.48) ^{cd}	44.44
Chlorantraniliprole 20 SC	30	33.33 (35.22) ^b	30.00	48.48 (44.13) ^{cd}	36.82	48.18 (43.95) ^{bc}	34.85
Novaluron 10 EC	75	20.00 (26.57) ^b	16.67	26.67 (31.00) ^b	15.00	36.67 (37.22) ^b	23.33
Bifenthrin 10 EC	50	40.71 (39.53) ^b	37.38	56.43 (48.72) ^d	44.76	60.48 (51.15) ^d	47.14
Untreated control	-	3.33 (6.14) ^a	0.00	11.67 (19.31) ^a	0.00	13.33 (21.14) ^a	0.00

*Mean of three replications; HAT – Hour after treatment
 In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT
 Figures in parentheses are arcsine $\sqrt{\text{Per cent transformed values}}$

Table 70. Toxicity of pyridine derivative 20 SC to rock bee, *Apis dorsata* Fabricius

Treatment	Dose (g a.i. ha ⁻¹)	1HAT		12 HAT		24 HAT	
		Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality
Pyridine derivative 20 SC	40	16.67 (23.86) ^b	26.67 (30.79) ^b	23.33	36.67	36.67 (37.22) ^b	30.00
Pyridine derivative 20 SC	50	30.00 (33.21) ^c	40.00 (39.15) ^{bc}	36.67	40.00	46.67 (43.08) ^{bc}	40.00
Pyridine derivative 20 SC	60	30.00 (33.21) ^c	43.33 (41.15) ^{bc}	40.00	40.00	46.67 (43.08) ^{bc}	40.00
Chlorantraniliprole 20 SC	30	36.67 (37.22) ^c	43.33 (41.15) ^{bc}	40.00	40.00	53.33 (46.92) ^c	46.67
Novaluron 10 EC	75	20.00 (26.57) ^b	33.33 (35.22) ^{bc}	30.00	30.00	36.67 (37.22) ^b	30.00
Bifenthrin 10 EC	50	40.00 (39.15) ^c	50.00 (45.00) ^c	46.67	46.67	63.33 (52.78) ^d	56.67
Untreated control	-	0.00 (0.00) ^a	3.33 (6.14) ^a	0.00	0.00	6.67 (12.29) ^a	0.00

Mean of three replications; HAT – Hour after treatment
 In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT
 Figures in parentheses are arcsine $\sqrt{\text{Per cent transformed values}}$

Table 71. Toxicity of pyridine derivative 20 SC to Indian bee, *Apis cerana indica* Fabricius

`Treatment	Dose (g a.i. ha ⁻¹)	1HAT		12 HAT		24 HAT	
		Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality
Pyridine derivative 20 SC	40	11.20 (19.54) ^b	16.61	20.32 (26.50) ^b	16.61	41.11 (39.83) ^{bc}	33.70
Pyridine derivative 20 SC	50	11.57 (16.28) ^b	27.31	31.02 (33.72) ^b	27.31	44.29 (41.71) ^{bc}	36.88
Pyridine derivative 20 SC	60	12.17 (20.38) ^b	31.42	35.12 (36.22) ^{bc}	31.42	46.30 (42.82) ^c	38.89
Chlorantraniliprole 20 SC	30	13.65 (21.58) ^b	32.80	36.51 (37.14) ^{bc}	32.80	63.49 (52.86) ^d	56.09
Novaluron 10 EC	75	8.93 (14.30) ^b	18.70	22.41 (28.23) ^b	18.70	29.44 (32.83) ^b	22.04
Bifenthrin 10 EC	50	18.65 (25.43) ^b	47.29	50.99 (45.55) ^c	47.29	66.27 (54.61) ^d	58.86
Untreated control	-	0.00 (0.00) ^a	0.00	3.70 (6.49) ^a	0.00	7.41 (12.98) ^a	0.00

*Mean of three replications; HAT – Hour after treatment
 In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT
 Figures in parentheses are arcsine $\sqrt{\text{Per cent transformed values}}$

Table 72. Effect of pyridine derivative 20 SC on the growth of *Trichoderma viride* Persoon

Treatment	Dose (g a.i. ha ⁻¹)	<i>T. viride</i> (mm)		
		24 HAI	48 HAI	72 HAI
Pyridine derivative 20 SC	40	22.67 (4.81) ^{ab}	22.33 (4.83) ^b	24.60 (5.01) ^b
Pyridine derivative 20 SC	50	19.50 (4.47) ^{bc}	20.83 (4.62) ^b	21.97 (4.74) ^c
Pyridine derivative 20 SC	60	16.83 (4.16) ^{cd}	17.40 (4.23) ^c	19.07 (4.42) ^d
Chlorantraniliprole 20 SC	30	13.67 (3.76) ^{de}	14.83 (3.92) ^{cd}	16.00 (4.06) ^e
Novaluron 10 EC	75	11.73 (3.50) ^e	12.17 (3.56) ^d	13.90 (3.79) ^f
Bifenthrin 10 EC	50	11.83 (3.51) ^e	12.07 (3.54) ^d	13.50 (3.74) ^f
Untreated control	-	26.50 (5.20) ^a	36.33 (6.07) ^a	41.00 (6.44) ^a

HAI - Hours after Inoculation

Table 73. Effect of pyridine derivative 20 SC on the growth of *Pseudomonas fluorescens* Migula

Treatments	Dose (g a.i. ha ⁻¹)	<i>P. fluorescens</i>		
		12 HAI	24 HAI	48 HAI
Pyridine derivative 20 SC	40	++	++	++
Pyridine derivative 20 SC	50	++	++	++
Pyridine derivative 20 SC	60	+	++	++
Chlorantraniliprole 20 SC	30	+	++	++
Novaluron 10 EC	75	+	++	++
Bifenthrin 10 EC	50	+	++	++
Untreated control	-	++	++	++

HAI - Hours after Inoculation

Single + indicates the growth of bacteria in one streak

Double + indicates the growth of bacteria in two streaks

Table 74. Effect of pyridine derivative 20 SC on the growth of *Beauveria bassiana* Balsamo

Treatments	Dose (g a.i. ha ⁻¹)	<i>B. bassiana</i> (mm)	
		5 DAI	10 DAI
Pyridine derivative 20 SC	40	8.23 (2.96) ^b	12.61 (3.62) ^b
Pyridine derivative 20 SC	50	6.83 (2.71) ^{bc}	9.33 (3.14) ^{bc}
Pyridine derivative 20 SC	60	5.67 (2.48) ^{bc}	7.00 (2.74) ^c
Chlorantraniliprole 20 SC	30	3.73 (2.06) ^{cde}	5.33 (2.42) ^d
Novaluron 10 EC	75	2.77 (1.81) ^{de}	4.50 (2.24) ^d
Bifenthrin 10 EC	50	2.40 (1.70) ^{de}	4.23 (2.18) ^d
Untreated control	-	13.67 (3.76) ^a	18.50 (4.36) ^a

DAI - Days after Inoculation

Table 75: Main-Chain Root Mean Square Deviation (RMSD) among ryanodine receptors

Protein Structure	<i>H. armigera</i>	<i>A. mellifera</i>	<i>T. castaneum</i>	<i>B. cucurbitae</i>	<i>S. furcifera</i>
<i>Helicoverpa armigera</i>	0	8.544 Å	5.125 Å	7.675 Å	6.358 Å
<i>Apis mellifera</i>	8.544 Å	0	7.103 Å	8.319 Å	11.948 Å
<i>Tribolium castaneum</i>	5.125 Å	7.103 Å	0	5.079 Å	6.661 Å
<i>Bactrocera cucurbitae</i>	7.675 Å	8.319 Å	5.079 Å	0	9.815 Å
<i>Sogatella furcifera</i>	6.358 Å	11.948 Å	6.661 Å	9.815 Å	0



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TOXICITY OF PYRIDINE DERIVATIVE 20 SC (NEW CHEMISTRY OF ANTHRANILIC DIAMIDE INSECTICIDE) TO HONEYBEES

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ABSTRACT:

Laboratory studies were carried to assess the toxicity of pyridine derivative 20 SC to honey bees, an anthranilic diamide insecticide by contact method in Tamil Nadu Agricultural University, Coimbatore during 2013 - 2014. Pyridine derivative 20 SC at 40, 50 and 60 g a.i.ha⁻¹ caused 13.33, 16.67 and 26.67 per cent mortality, respectively to *Trigona iridipennis* Smith after 1 hour after treatment (HAT) and it increased to 16.67, 26.67 and 33.33 and 23.33, 33.33 and 36.67 per cent, respectively after 12 and 24 HAT. At 24 HAT *Apis dorsata* F. recorded the per cent mortality of less than 50 per cent, whereas *Apis cerana indica* F. recorded more than 50 per cent which is highly toxic. Toxicity of standard checks chlorantraniliprole 20 SC, novaluron 10 EC and bifenthrin 10 EC were in the range of 6.67 to 58.86 per cent at 24 HAT, respectively.

KEY WORDS: Pyridine derivative, Toxicity, Honeybees, Mortality.

INTRODUCTION:

Pyridine derivative 20 SC is a compound with a new chemistry belonging to the anthranilic diamide group developed by Bayer Crop Science India Ltd. with a novel and very specific mode of action. Anthranilic diamide insecticides activate ryanodine receptors by stimulating the release of calcium stores from the sarcoplasmic reticulum of muscle cells (i.e. for chewing insect pests) causing paralysis and ultimately death of sensitive species (Cordova *et al.*, 2006). Chlorantraniliprole, a diamide insecticide has differential selectivity for insect ryanodine receptors that explains the outstanding profile of low mammalian toxicity (Lahm *et al.*, 2007). Approximately 90 percent of all flowering plants require pollinators to survive. Honey bees have been considered to be the most ecologically and economically significant pollinator globally. In agriculture, nearly one third of pollination is accomplished by honeybees. Hence, it is essential to study the effect of pyridine derivative 20 SC on honey bees.

MATERIAL AND METHODS:

Laboratory experiments were conducted to assess the safety of pyridine derivative 20 SC to the indian bee, *Apis cerana indica* F., rock bee, *Apis dorsata* F. and dammer bee or stingless bee, *Trigona iridipennis* Smith. The experiment was conducted in completely randomized design (CRD) with seven treatments and each treatment was replicated three times. The pyridine derivative 20 SC was evaluated @ 40, 50 and 60 g a.i. ha⁻¹, along with standard checks like chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹, novaluron 10 EC @ 75 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ by contact toxicity method. Different concentrations of pyridine derivative 20 SC and standard checks were prepared using distilled water. Plastic containers with perforations on the sides and lid were used for the experiment to allow adequate aeration for the bees. Filter papers of diameter 10cm were placed inside the container and sprayed with one ml of insecticide solution and then allowed to dry for 15 min. Honey bees were kept in refrigerator for five minutes prior to test to calm them and transferred @ 10 per container. After exposure for an hour, the insecticide treated filter papers were removed and honey bees were transferred to fresh containers. Honey bees were fed with 40 per cent sucrose solution soaked in cotton wool. The bee mortality was observed at 1, 12 and 24 h after treatment and expressed as corrected per cent mortality. The mean values were separated using Duncan's Multiple Range Test (DMRT). (Duncan, 1951).

RESULTS AND DISCUSSION:

Laboratory test revealed that pyridine derivative at 40, 50, 60 g a.i. ha⁻¹ and the standard checks, chlorantraniliprole at 30 g a.i. ha⁻¹, novaluron at 75 g a.i. ha⁻¹ caused less than 50 per cent mortality in *T. iridipennis* after 24 hours. The standard checks, novaluron 10 EC @ 75 g a.i. ha⁻¹ and

chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ recorded 20.00 and 33.33 per cent mortality, respectively. Standard check bifenthrin 10 EC at 50 g a.i. ha⁻¹ recorded the highest mortality of 56.67 per cent at 24 HAT (Table 1).

A similar trend of mortality was noticed in *A. dorsata*. Among the different pyridine derivative treatments, the mortality of bees ranged from 16.67 to 46.67 per cent. Pyridine derivative @ 40, 50 and 60 g a.i. ha⁻¹ recorded the mortality of 30.00, 40.00 and 46.67 per cent at 24 HAT, respectively (Table 2). Standard checks novaluron 10 EC @ 75 g a.i. ha⁻¹, chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ recorded 20.00, 30.00, 30.00; 30.00, 40.00, 40.00 and 40.00, 46.67, 56.67 per cent at 1, 12 and 24 HAT, respectively. (Table 2).

In Indian bee pyridine derivative @ 40 g a.i. ha⁻¹ registered mortality of 13.65, 16.61 and 36.88 per cent at 1, 12 and 24 HAT, respectively. Pyridine derivative @ 50 g a.i. ha⁻¹ registered 11.57, 27.31 and 38.89 per cent at 1, 12 and 24 HAT, respectively. Maximum mortality was obtained when the bees were exposed to bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (18.65, 47.29 and 58.86 % at 1, 12 and 24 HAT, respectively) (Table 3). The present findings corroborated with the findings of Axel Dinter *et al.* (2009) who reported that chlorantraniliprole tested against honey bees showed low intrinsic toxicity to honey bees. The oral and contact LD₅₀ values were > 0.027 and > 0.005 µg chlorantraniliprole bee⁻¹. Similar results were obtained by Thilagam (2006) who stated that, among the bees tested, little bees were more affected due to the application of flubendiamide than Indian and Italian bees. Among the flubendiamide treatments, the lowest mortality of italian bees was observed in flubendiamide @ 36 g a.i. ha⁻¹ (9.17%) followed by flubendiamide @ 48 g a.i. ha⁻¹ (14.57 %) and 60 g a.i. ha⁻¹ (17.59 %) at 12 hours after treatment. The effect of pyridine derivative 20 SC on three different species of honey bees showed that the dose at 40 and 50 g a.i. ha⁻¹ recorded less than 50 per cent mortality of indian bees, rock bees and dammer bees. In the field condition, honey bees would not get in contact with the insecticide for longer time, hence the effect of pyridine derivative 20 SC on honey bees in the field condition would even be lesser. It is evident from the present study, pyridine derivative will provide excellent tools for integrated pest management (IPM) programmes to conserve pollinating honey bees and where there is a continuous need to tackle pest problems.

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Table 1. Toxicity of pyridine derivative 20 SC to dammer bee, *Trigona iridipennis* Smith

Treatments	Dose (g a.i. ha ⁻¹)	1HAT		12 HAT		24 HAT	
		Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality
Pyridine derivative 20 SC	40	16.67 (23.56) ^{bc}	13.33 (21.14) ^c	20.00 (26.57) ^b	16.67 (23.86) ^b	30.00 (33.21) ^{bc}	23.33 (28.78) ^b
Pyridine derivative 20 SC	50	20.00 (26.57) ^{cd}	16.67 (23.86) ^{cd}	30.00 (33.21) ^{bc}	26.67 (31.00) ^{bc}	40.00 (39.23) ^c	33.33 (35.22) ^c
Pyridine derivative 20 SC	60	30.00 (33.21) ^{de}	26.67 (31.00) ^{de}	36.67 (37.22) ^c	33.33 (35.01) ^c	43.33 (41.15) ^c	36.67 (37.22) ^c
Chlorantraniliprole 20 SC	30	23.33 (28.78) ^{cd}	20.00 (26.57) ^{cd}	36.67 (37.22) ^c	33.33 (35.22) ^c	40.00 (39.23) ^c	33.33 (35.22) ^c
Novaluron 10 EC	75	10.00 (18.43) ^b	6.67 (12.29) ^b	20.00 (26.57) ^b	16.67 (23.86) ^b	26.67 (31.00) ^b	20.00 (26.07) ^b
Bifenthrin 10 EC	50	36.67 (37.22) ^e	33.33 (35.01) ^e	43.33 (41.15) ^c	40.00 (36.93) ^c	63.33 (52.78) ^d	56.67 (48.85) ^d
Untreated control	-	3.33 (6.14) ^a	0.00 (0.00) ^a	3.33 (6.14) ^a	0.00 (0.00) ^a	6.67 (12.29) ^a	0.00 (0.00) ^a

*Mean of three replications; HAT – Hour after treatment
 In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT
 Figures in parentheses are arcsine $\sqrt{\text{Per cent transformed values}}$

Table 2. Toxicity of pyridine derivative 20 SC to Rock bee, *Apis dorsata* F.

Treatments	Dose (g a.i. ha ⁻¹)	1HAT		12 HAT		24 HAT	
		Per cent mortality*	Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality	
Pyridine derivative 20 SC	40	16.67 (23.86) ^b	26.67 (30.79) ^b	23.33 (28.78) ^b	36.67 (37.22) ^b	30.00 (33.00) ^b	
Pyridine derivative 20 SC	50	30.00 (33.21) ^c	40.00 (39.15) ^{bc}	36.67 (36.93) ^{bcd}	46.67 (43.08) ^{bcd}	40.00 (39.23) ^{bc}	
Pyridine derivative 20 SC	60	36.67 (37.22) ^c	43.33 (41.15) ^{bc}	40.00 (39.15) ^{cd}	53.33 (46.92) ^c	46.67 (43.08) ^{cd}	
Chlorantraniliprole 20 SC	30	30.00 (33.21) ^c	43.33 (41.15) ^{bc}	40.00 (39.23) ^{cd}	46.67 (43.08) ^{bc}	40.00 (39.15) ^{bc}	
Novaluron 10 EC	75	20.00 (26.57) ^b	33.33 (35.22) ^{bc}	30.00 (33.00) ^{bc}	36.67 (37.22) ^b	30.00 (33.21) ^b	
Bifenthrin 10 EC	50	40.00 (39.15) ^c	50.00 (45.00) ^c	46.67 (43.08) ^d	63.33 (52.78) ^d	56.67 (48.93) ^d	
Untreated control	-	0.00 (0.00) ^a	3.33 (6.14) ^a	0.00 (0.00) ^a	6.67 (12.29) ^a	0.00 (0.00) ^a	

*Mean of three replications; HAT – Hour after treatment
 In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT
 Figures in parentheses are arcsine $\sqrt{\text{Per cent}}$ transformed values

Table 3. Toxicity of pyridine derivative 20 SC to Indian bee, *Apis cerana indica* F

Treatments	Dose (g a.i. ha ⁻¹)	1HAT		12 HAT		24 HAT	
		Per cent mortality*	Per cent mortality*	Corrected mortality	Per cent mortality*	Corrected mortality	
Pyridine derivative 20 SC	40	13.65 (21.58) ^b	20.32 (26.50) ^b	16.61 (16.05) ^b	44.29 (41.71) ^{bc}	36.88 (37.37) ^c	
Pyridine derivative 20 SC	50	11.57 (16.28) ^b	31.02 (33.72) ^b	27.31 (19.36) ^{cd}	46.30 (42.82) ^c	38.89 (38.55) ^c	
Pyridine derivative 20 SC	60	12.17 (20.38) ^b	36.51 (37.14) ^{bc}	32.80 (22.72) ^{cd}	63.49 (52.86) ^d	56.09 (48.50) ^d	
Chlorantraniliprole 20 SC	30	11.20 (19.54) ^b	35.12 (36.22) ^{bc}	31.42 (20.99) ^{cd}	41.11 (39.83) ^{bc}	33.70 (35.21) ^{bc}	
Novaluron 10 EC	75	8.93 (14.30) ^b	22.41 (28.23) ^b	18.70 (14.69) ^b	29.44 (32.83) ^b	22.04 (27.96) ^b	
Bifenthrin 10 EC	50	18.65 (25.43) ^b	50.99 (45.55) ^c	47.29 (26.90) ^c	66.27 (54.61) ^d	58.86 (50.17) ^d	
Untreated control	-	0.00 (0.00) ^a	3.70 (6.49) ^a	0.00 (3.51) ^a	7.41 (12.98) ^a	0.00 (0.13) ^c	

*Mean of three replications; HAT – Hour after treatment
 In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT
 Figures in parentheses are arcsine $\sqrt{\text{Per cent}}$ transformed values



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EFFECT OF PYRIDINE DERIVATIVE 20 SC (A NEW CHEMISTRY OF ANTHRANILIC DIAMIDE INSECTICIDE) AND THREE COMMERCIAL INSECTICIDES ON *CHRYSOPERLA ZASTROW SILLEMI* (ESBEN - PETERSEN) GRUBS

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ABSTRACT:

In a study conducted at Tamil Nadu Agricultural University, Coimbatore toxicity of some new chemistry insecticide pyridine derivative 20 SC @ 60, 50 and 40 g a.i. ha⁻¹, chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹, novaluron 10 EC @ 75 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ was tested on eggs of *Chrysoperla zastrow sillemi* in laboratory. The observation on percent mortality of larvae were recorded after 24 and 48 hours after treatment. The results showed that bifenthrin 10 EC @ 50 g a.i. ha⁻¹ and pyridine derivative 20 SC at higher dose 60 g a.i. ha⁻¹ were found to be toxic to the *Chrysoperla* larvae with mortality ranging from 23.33 to 30.00 per cent. The application of pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ proved to be comparatively safer with 10.00 per cent larval mortality, 83.33 and 76.67 per cent pupation and adult emergence respectively.

KEY WORDS: Pyridine Derivative, Commercial Insecticides, *Chrysoperla Zastrow Sillemi*.

INTRODUCTION:

Biological control agents can cause substantial decrease in pest population numbers. Green lacewing is a generalist and widely distributed predator of many soft bodies insect pests. *Chrysoperla carnea* Stephens (green lacewing) is an important natural enemy, belonging to family chrysopidae, order

Neuroptera. The natural enemies are living organisms that kill or weaken the pests and cause their premature death or reduce their reproductive potential. A natural enemy feeds on its prey or host and thus promotes its own population. Natural enemies not only prevent the insects from attaining pest status but also reduce the damage potential of pests. Hence, their manipulation in pest management programmes has proved very helpful in controlling pest population. Their agricultural importance lies in their carnivorous habits. The larvae are important predators, especially to control aphids. Some are terrestrial, feeding on jassids, psyllids, aphids, coccids, mites, etc. and others are aquatic. It is rare in the tropics to find a large colony of aphids without at least some neuropterous larvae feeding on them. One larva may devour as many as five hundred aphids in its life and there is no doubt that they play an important part in the natural control of many small homopterous pests (Hydrone and Whitecomb, 1979; Legaspi, 1994 and Michaud, 2001). It is a very important biological control agent due to its tolerance to wide ranges of ecological factors. Croft and Brown (1975) reviewed that indiscriminate use of pesticides not only results in the development of insecticide resistance but also eliminates the natural enemies of insect pests. Therefore, it is important to examine the possible disruptive effects of candidate insecticides on beneficial insects, and to determine the insecticides compatible with key biological control agents (Stapel *et al.*, 2000). Many workers have revealed the importance of *C. z. sillemi* in biological control and the inevitability of chemicals to be applied in synchronization as a prerequisite of IPM. The purpose of work reported here was to evaluate effect of pyridine derivative 20 SC against larvae, pupae and adult of *C. z. sillemi*.

MATERIALS AND METHODS:

Chrysoperla zastrow sillemi eggs and grubs were procured from Biological Control unit, Tamil Nadu Agricultural University, Coimbatore where the *C. z. sillemi* was mass reared with *C. cephalonica* eggs as feed. Grubs of *C. z. sillemi* were reared in galvanized iron (GI) basins (30 cm dia. x 12 cm ht) at 250 grubs per basin covered with kada cloth. About 25c eggs of *C. cephalonica* were provided as feed for the grubs per basin on alternate days. Usually after five feedings, the larvae pupated into white coloured round silken cocoon. The cocoons were collected and transferred into one litre plastic container with wire mesh window for emergence of adults.

The adults were collected and transferred to GI troughs, lined inside with brown sheets for collecting the eggs. The trough was covered with muslin cloth and was secured with the help of a rubber band and thread. Over the cloth covering, two bits of sponge (2.5 cm²) dipped in water were kept besides an artificial protein rich diet in the form of semi solid paste was smeared as food for the adults. This diet consisted one part of fructose, one part of honey and one part of Protinex[®] with water and made into a

paste (Swappiappan, 1996). From the GI troughs, the brown paper sheets with eggs were removed and used for further culturing or hatchability test.

Experiment was conducted under laboratory conditions to assess the effect of pyridine derivative 20 SC on the eggs of *C. z. sillemi*, as per the method described by Krishnamoorthy (1985). The eggs along with stalk laid on brown paper strips were sprayed with insecticides as in table 1 using a hand atomizer. Each treatment was replicated thrice with 10 eggs per treatment. Untreated check was maintained by spraying distilled water alone Number of grubs hatched in each treatment was recorded and per cent hatchability was worked out by using the formula,

$$\text{Per cent hatchability} = \frac{\text{No. of grubs hatched}}{\text{Observations}} \times 100$$

Observations were recorded on per cent mortality of the grubs (24 and 48 h after treatment), pupation (%) and adult emergence (%) were worked as above.

RESULTS AND DISCUSSION:

The results on the effect of pyridine derivative 20 SC on *C. z. sillemi* grubs revealed that maximum grub mortality was obtained when the grubs were exposed to pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ with mortality of 23.33 and 26.67 per cent at 24 and 48 HAT, respectively. Pyridine derivative 20 SC @ 50 and 40 g a.i. ha⁻¹ recorded 10.00, 10.00 and 3.33, 10.00 per cent at 24 and 48 HAT, respectively. No mortality was observed in untreated check (Table 1). Among the different treatments, pyridine derivative 20 SC @ 40 g a.i.ha⁻¹ recorded 86.67 per cent pupation and 83.33 per cent adult emergence followed by pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (83.33 and 76.67%). Untreated control recorded 100 per cent pupation and adult emergence. Pupation and adult emergence rates were lowest in pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (73.33, 66.67 and 73.33, 60.00%, respectively) (Table 1). The above finding confirms that pyridine derivative 20 SC @ 50 and 40 g a.i. ha⁻¹ did not adversely affected the growth and development of *C. z. sillemi* at the grub stage, while very little effect to the adults. The present findings are in conformity with Ameta *et al.* (2011) who reported with spray of flubendiamide 480 SC @ 50, 75 and 100 ml ha⁻¹, indoxacarb 14.5 SC at 500 ml ha⁻¹ and spinosad 187.5 ml ha⁻¹ did not cause adverse effects on the population of grubs and adults of *C. carnea*. Dilbar *et al.* (2012) reported that, application of flubendiamide proved to be comparatively safer with 8 to 16 per cent mortality of first larval stage of *C. carnea* at all intervals (3, 6, 12 and 24 hours) except 48 hours.

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Table 1. Toxicity of pyridine derivative 20 SC on the grub of *C. z. sillemi* by dry film method

Treatments	Dose (g a.i. ha ⁻¹)	Mortality [*] (%)		Pupation [*] (%)	Adult emergence [*] (%)
		24 HAT	48 HAT		
Pyridine derivative 20 SC	40	3.33 (6.14) ^{ab}	10.00 (18.43) ^{bc}	86.67 (68.86) ^b	83.33 (66.64) ^b
Pyridine derivative 20 SC	50	10.00 (15.00) ^{abc}	10.00 (15.00) ^b	83.33 (66.14) ^{bc}	76.67 (61.22) ^{bc}
Pyridine derivative 20 SC	60	23.33 (28.29) ^c	26.67 (31.00) ^{cd}	73.33 (59.00) ^{bc}	66.67 (54.78) ^{cd}
Coragen 20 SC	30	13.33 (21.14) ^{bc}	20.00 (26.57) ^{cd}	80.00 (63.43) ^{bc}	70.00 (57.00) ^{cd}
Novaluron 10 EC	75	3.33 (6.14) ^{ab}	13.33 (21.14) ^b	76.67 (61.22) ^c	70.00 (56.79) ^{cd}
Bifenthrin 10 EC	50	23.33 (28.78) ^c	30.00 (33.21) ^d	73.33 (59.00) ^c	60.00 (50.85) ^d
Untreated control	-	0.00 (0.00) ^a	0.00 (0.00) ^a	100.00 (90.00) ^a	100.00 (90.00) ^a

^{*}Mean of three replications; HAT - Hour after treatment
In a column means followed by a common letter are not significantly different at P = 0.05 by DMRT
Figures in parentheses are arcsine $\sqrt{\text{Per cent}}$ transformed values.

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ABSTRACT

STUDIES ON BIOEFFICACY, SAFETY, PHYTOTOXICITY AND ARTHROPOD DIVERSITY OF PYRIDINE DERIVATIVE 20 SC IN TOMATO AND RICE

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Studies were conducted in field to evaluate the bioefficacy, safety and phytotoxicity of pyridine derivative 20 SC on tomato and rice, selective toxicity to natural enemies, compatibility with microorganisms and characterization of ryanodine receptor in the target pests under laboratory conditions.

In field experiments on tomato, pyridine derivative 20 SC @ 50 and 60 g a.i. ha⁻¹ were effective in reducing the fruit damage which was in the range of 54.13 to 58.88 per cent during first season and 51.44 to 56.35 per cent during second season and were better than the standard checks viz., chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and novaluron 10 EC @ 75 g a.i. ha⁻¹. Application of pyridine derivative 20 SC @ 50 and 60 g a.i. ha⁻¹ effected reduction of *Helicoverpa armigera* Hubner population to the extent of 91.82 - 94.60 and 86.96 - 94.20 per cent in first season and second seasons, respectively. Similarly, pyridine derivative 20 SC @ 50 and 60 g a.i. ha⁻¹ recorded significant reduction of serpentine leafminer damage and population.

Field experiments conducted at Polluvampatti and Thennamanallur on rice revealed that foliar application of pyridine derivative 20 SC @ 50 and 60 g a.i. ha⁻¹ significantly

reduced the damage caused by stem borer (52.03 - 54.68 and 47.79 - 52.80 per cent in first and second seasons, respectively) and leaf folder (35.74 - 40.72 and 26.90 - 31.25 per cent in first and second seasons, respectively). Pyridine derivative 20 SC at all tested doses were comparatively less toxic to natural enemies viz., coccinellids and spiders in tomato and spiders, mirids and rove beetle in rice when compared with the conventional insecticide bifenthrin 10 EC. Foliar application of pyridine derivative 20 SC (60, 120 and 240 g a.i. ha⁻¹) in tomato and rice under field conditions did not cause any phytotoxicity symptoms. In both the locations, pyridine derivative treated plots resulted in increased tomato and rice yield than conventional insecticides.

Arthropod biodiversity in tomato ecosystem revealed that a total of 2760 individuals of arthropods belonging to 48 families and 14 orders was observed in both sprayed and unsprayed tomato field. Unsprayed tomato showed higher species richness, abundance and distribution at ordinal, familial, generic and species level than sprayed field. The species richness indices based on Species number, Fishers Alpha index, Margalef's D index, Q Statistic, Brillouin diversity index and Shannon-Weiner index and dominance indices viz., Simpson's index, McIntosh index and Berger Parker index were higher in unsprayed tomato than sprayed field. Beta diversity indices based on ordinal, familial, generic and species level indicated higher index values in sprayed field than unsprayed tomato field.

The arthropods in rice ecosystems revealed that a total of 5,095 individuals belonging to 90 species under 84 genera, 54 families and 11 orders was observed from two classes viz., Insecta and Arachnida. Under Insecta, Hemiptera and Hymenoptera were predominant in terms of individuals of exopterygota and endopterygota, respectively. Under Arachnida, Araneae was the most dominant order with majority of the individuals belong to Tetragnathidae. Unsprayed tomato showed higher species richness, abundance and distribution at ordinal, familial, generic and species level than sprayed field.

Laboratory experiments conducted at Insectary unit, Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore to study the safety of pyridine derivative 20 SC against parasitoids (*Trichogramma chilonis* Ishii and *Bracon hebetor* Say) and predators (*Chrysoperla zastrowi sillemi* Esben - Petersen and

coccinellids, *Cheilomenes sexmaculata* Fabricius) revealed that pyridine derivative 20 SC (40 and 50 g a.i. ha⁻¹) did not cause any adverse effect on the adult emergence and parasitization of *T. chilonis* and found to be the least toxic to larval parasitoid, *B. hebetor*. Pyridine derivative 20 SC @ 40 and 50 g a.i. ha⁻¹ recorded 83.22 and 79.91 per cent hatching of *C. zastrowi sillemi*, respectively. All the test doses of pyridine derivative 20 SC caused less than 50 per cent mortality to *C. zastrowi sillemi* grubs in dry film method and it was found to be safe. It was also found to be relatively safe to grubs and adults of *C. sexmaculata* with less than 50 per cent mortality. Pyridine derivative 20 SC @ 40 and 50 g a.i. ha⁻¹ exhibited less toxicity to dammer bees, little bees, rock bees and Indian bees. Pyridine derivative 20 SC at test doses (40, 50 and 60 g a.i. ha⁻¹) was compatible with *Trichoderma viride* Persoon, *Pseudomonas fluorescens* Migula and *Beauveria bassiana* Balsamo. The protein structure modelling and phylogenetic tree analysis resulted that RyR in different insect species viz., *H. armigera*, *Apis mellifera* Linnaeus, *Tribolium castaneum* (Herbst), *Bactrocera cucurbitae* (Coquillett) and *Sogatella furcifera* (Horvath) showed greater variation.

CHAPTER I INTRODUCTION

Tomato (*Solanum lycopersicum* Linnaeus = *Lycopersicon esculentum* Mill) is one of the most important and widely grown vegetable crops of both tropics and subtropics. It is originally a native of tropical America from Peruvian and Mexican regions. This crop is cultivated over an area of 0.88 million ha with an annual production of 18.227 million tonnes and productivity of 20.7 tonnes per ha in India (Anonymous, 2013). On an average, about 10,800 tonnes of tomato is exported annually from India. China, USA, Turkey and Egypt are the other main commercial producers of tomatoes. It has varied climatic tolerance and it is rich in vitamins A and C. It also contains essential fat, mineral, fibre, oxalic acid, calcium, magnesium, phosphorus and iron. It performs well under an average monthly temperature of 21 to 23°C (Choudhary, 2000). Tomato can be used as salad and as processed foods like ketchup, sauce, paste, soup, etc. Today consuming tomato is greater than any other single fruit or vegetable and are one of the top selling vegetables throughout the world.

The crop is severely damaged by many insect pests and the major pests of tomato are tomato fruit borer, *Helicoverpa armigera* Hubner, whitefly, *Bemisia tabaci* (Gennadius), aphids, *Aphis gossypii* (Glover), leaf eating caterpillar, *Spodoptera litura* (Fabricius), thrips, *Thrips tabaci* Lindeman, American serpentine leafminer *Liriomyza trifolii* (Burgess) and two spotted red spider mite, *Tetranychus urticae* Koch. The tomato fruit borer is a polyphagous pest attacking cotton, okra, chilli, cabbage, pigeon pea, gram, etc., throughout the world as well as in India. Due to its high fecundity, polyphagous nature and quick adaptation against insecticides, control of this pest with any single potent toxicant for a long time is difficult and rather impossible. Now it has developed cross resistance to many popular insecticides. To control this insect pest and to save the crop, pesticides are being used in large quantities by human being (Ghosh *et al.*, 2010). The annual crop loss due to *H. armigera* in India has been estimated at around Rs. 2,000 crores (Pawar *et al.*, 1999). An average incidence was found to cause 40 to 50 per cent loss (Yelsbelty and Gowda, 1998) on tomato. The larva of fruit borer feeds on foliage, floral buds, flowers and bores into fruits, thus making them unfit for human consumption.

The serpentine leaf miner, *L. trifolii* (Diptera: Agromyzidae), an invasive pest was accidentally introduced into India from the American sub-continent along with chrysanthemum cuttings. In India, it was initially recorded on 55 plant species (Viraktamath *et al.*, 1993) and later on about 79 species (Srinivasan *et al.*, 1995) that included pulses, oil seeds, vegetables, green manures, fodder and fibre crops. Further Galande *et al.* (2004) recorded on 16 new crops and 16 weed species. Adults puncture the leaves to lay the eggs and the larvae tunnel within the leaf and make characteristic serpentine mines. Extensive leaf mining activity reduces the photosynthetic capacity of the plants. Wolfenbarger and Wolfenbarger (1966) reported that tomato yields were reduced when each leaflet had one or more mines.

Rice (*Oryza sativa* L.) is the most important and staple food crop for more than two third of the population of India. The slogan “Rice is the Life” is most appropriate for India and plays a vital role in the national food security and is a means of livelihood for millions of rural households. During 2012-13 and 2013-14, the world rice production has increased by one per cent (from 472 MT to 476 MT), trade by eight per cent (from 38 million MT to 41 million MT) and consumption by three per cent (from 469 million MT to 481 million MT) (Anonymous, 2015). India leads the world in rice area with 41.85 m ha with a production of 102 MT, but productivity is only 75 per cent of the world average of 4.02 tonnes ha⁻¹ (Anonymous, 2011). The crop is prone to severe yield losses by both abiotic and biotic stresses to an extent of 46.4 per cent out of which 26.7 per cent is due to insect pests (Jayaraj, 1996). There are over 70 pests infesting rice in India and 20 are of regular occurrence (Pathak, 1975). In India, losses incurred due to the different insect pests of rice is to the tune of Rs. 5, 51,200 lakh rupees, which in turn comes out to 18.6 per cent of total loss. Among the various insect pests attacking rice, leaf folder and stem borer are important. The leaf folder complex comprises of eight species (Bradley, 1981; Mathew and Menon, 1984; Reissig *et al.*, 1985) among which, few has attained major pest status in the recent past and causes heavy yield loss when they damage the crops at tillering and boot leaf stages (Murugesan and Chelliah, 1983 a and b). Leaf folder, *Cnaphalocrocis medinalis* Guenee causes a loss of 60 to 70 per cent leaf damage (Kushwaha and Singh, 1984), 76.1 per cent in grain yield and 14.6 per cent in straw yield (Patel *et al.*, 1986) and thus significant in causing yield losses (Murugesan and Chelliah, 1986; Srivastava, 1989).

Eight species of stem borers of rice are known to be of significant importance in Asia (Hattori, 1971). They infest the crop from seedling to maturity and account for a larger share on the crop loss. The yellow stem borer, *Scirpophaga incertulas* Walker has assumed the number one pest status which attacks the crop at all growth stages (Pasulu *et al.*, 2002). It causes dead heart at active tillering stage and white ear at ear head stage. The extent of damage caused by the yellow stem borer alone ranged from 3 to 95 per cent (Ghose *et al.*, 1960) which leads to complete failure of the crop (Karthikeyan and Purushothaman, 2000).

Effective pest control is one of the interventions currently employed to minimize crop losses and to increase agricultural output. Since the Green Revolution, there has been a big increase in the use of synthetic pesticides to control insects, weeds and fungi and this, together with improved agricultural practices and crop varieties, has resulted in more than a doubling in crop production in the last 50 years (Pingali, 2012). One of the main drawbacks of increased chemical pesticide usage is the associated risks for adverse environmental impacts.

The second problem for pesticide sustainability is the development of resistance in target pests due to a high selection pressure imposed by frequent (and in many cases misapplied) spraying. For insecticides, it is estimated that around 600 insect and mite species are resistant to at least one class of currently used commercial compound (Bass and Field, 2011). Thus, there is a need for the development of novel methods of pest control and for the discovery of new and safer insecticidal chemistry with improved efficacy and toxicological profiles. These novel insecticides offer great scope as they could maintain high toxicity to insects at lower doses and are not likely to persist like the conventional group of insecticides (Tanaka *et al.*, 2000).

One such new group is phthalic acid diamide group, discovered as a novel class of insecticide having a unique chemical structure and showed excellent activity against a broad spectrum of lepidopterans. This compound has novel mode of action which binds and activates ryanodine receptors, resulting in depletion of intracellular calcium stores finally leading to muscle paralysis and death. In India, Bayer Crop Science, Mumbai has developed an insecticide, with a new chemistry of pyridine derivative 20 SC for use

against lepidopteran pests of tomato and rice. With the above background, research work was carried out on various aspects of pyridine derivative 20 SC on tomato and rice crops with the following objectives,

- ❖ To evaluate the pyridine derivative 20 SC against fruit borer and serpentine leaf miner in tomato and stem borer and leaf folder in rice.
- ❖ To study the phytotoxic effect of pyridine derivative 20 SC on tomato and rice.
- ❖ To study the safety of pyridine derivative 20 SC to natural enemies in tomato and rice ecosystem.
- ❖ To assess the arthropod biodiversity in pyridine derivative 20 SC sprayed and unsprayed tomato and rice ecosystem.
- ❖ Molecular characterization of insect ryanodine receptor

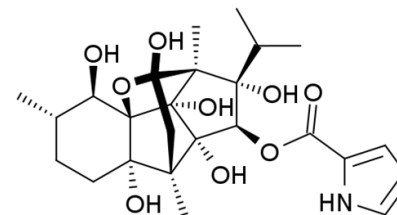
CHAPTER - II

REVIEW OF LITERATURE

The information available on bioefficacy, phytotoxicity, safety to natural enemies, pollinators and micro-organisms and molecular characterisation of pyridine derivative insecticide ryanodine as well as its effect on biodiversity of arthropods in tomato and rice ecosystems are reviewed in this chapter.

2.1. Mode of action

General chemical structure of ryanodine



Diamides are a relatively new class of synthetic insecticides that cause an uncontrolled calcium release within insect muscle cells and disrupt the intracellular calcium homeostasis in insects by selectively targeting and activating ryanodine receptors (RyRs), resulting in feeding cessation, muscle paralysis and death (Lahm *et al.*, 2009). Compounds belonging to this class of insecticides are flubendiamide, chlorantraniliprole and cyantraniliprole. Since their introduction to the market in 2007, diamides have been a great commercial success, with sales of chlorantraniliprole alone reaching 500 million US dollars in 2011 (Trocza *et al.*, 2012). Until the introduction of diamides, there has been no successful commercialisation of insecticides targeting the RyRs or any other aspects of cell calcium signalling and homeostasis (Cordova *et al.*, 2006). Ryanodine, a plant alkaloid extracted from the South American shrub, *Ryania speciosa* (Vahl.), has been used as a botanical insecticide for almost 60 years. However, its high toxicity to mammals made it unsuitable for wide-scale use (Anonymous, 1999). Attempts to create commercial compounds based on ryanodine with improved toxicological profile towards vertebrates, had only moderate success (Usherwood and Vais, 1995). Ryanodol and 9,

21-didehydroryanodol had low vertebrate toxicity and did not become economically important chemicals (Sattelle *et al.*, 2008). Unlike ryanodine, 9, 21-didehydroryanodol does not cause muscle contraction, but inhibits contraction through the modulation of potassium channels (Usherwood and Vais, 1995). Another unrelated compound, Verticillide (isolated from *Verticillium* sp), has ten times higher affinity towards cockroach RyRs over a mouse RyR1 isoform; however, the nature of the interaction with RyRs is unknown (Shiomi *et al.*, 2010).

The successful commercialisation of flubendiamide by Nihon Nohyaku and Bayer Crop Science in 2007 and a year later, chlorantraniliprole by DuPont (Jeanguenat, 2013), led to the creation of new mode of action group (Group 28) by the Insecticide Resistance Action Committee (IRAC) (Sattelle *et al.*, 2008). The initial lead to the discovery of flubendiamide (a benzene dicarboxamide or a phthalic acid diamide) came from the pyrazine dicarboxamide herbicide program of Japanese company, Nihon Nohyaku (Lahm *et al.*, 2009). The compound was then co-developed with Bayer Crop Science, after it displayed excellent potency towards broad range of lepidopteran insects. Initial studies of the symptoms of poisoning disclosed gradual contraction of the lepidopteran insect body without convulsions, suggesting a novel mode of action manifested outside of the central nervous system and similar to symptoms observed for ryanodine (Tohnishi *et al.*, 2005). Flubendiamide also demonstrated good control of lepidopterans which already showed resistance to existing classes of insecticides, with bioassays on *Plutella xylostella* (L.) larvae resistant to pyrethroids, organophosphates, carbamates and benzoylphenylurea (chitin synthesis modulator) giving a level of control equal to the susceptible strain, with no cross resistance apparent. The novel compound also exhibited very low mammalian toxicity, with an acute LD₅₀ in rats (>2000 mg kg⁻¹) and a consistent lack of mutagenic properties. Further investigation on the mode of action of flubendiamide by analysing gut muscles from the tobacco budworm, *Heliothis virescens* (Fab.), showed no muscle contraction, whilst maintaining nervous system activity. The molecular target was identified to be the RyRs through fluorescent calcium release assays done on (i) single *H. virescens* neurons and (ii) CHO cells (Chinese Hamster Ovary) expressing *Drosophila melanogaster* (Meig.) RyRs (Kintscher *et al.*, 2006 and 2007). Additionally, flubendiamide was shown to have a stimulating effect on Ca²⁺ pump activity, revealing a close

relationship between luminal calcium concentration and activation of calcium pumps and the negative effect of insecticide binding on cellular Ca²⁺ homeostasis (Masaki *et al.*, 2006). The high specificity of flubendiamide towards insect channels was also confirmed by calcium release assays on different mammalian cell lines naturally expressing various isoforms of the receptor (Kintscher *et al.*, 2006). Thus, flubendiamide became the first commercial synthetic insecticide with a novel mode of action targeting RyRs and it entered the market in 2007 (Nauen, 2006).

2.1.1. Chlorantraniliprole and cyantraniliprole

Chlorantraniliprole (an anthranilic diamide), developed by M/s DuPont Crop Protection, shows broader insecticidal activity in comparison to flubendiamide, giving good control not only to Lepidoptera but also to Coleoptera, Diptera and Isoptera. Flubendiamide and chlorantraniliprole had excellent toxicological profile, with an LD₅₀ value of acute oral toxicity of >500 mg kg⁻¹ of body weight for vertebrates and has high efficacy on insects resistant to other classes of insecticides. In cellular assays, it was not active against mammalian RyR₁ and RyR₂ isoforms and showed up to 2000-fold decreased potency towards RyR₂ in comparison to insect channels (Lahm *et al.*, 2009). Apart from the high potency of chlorantraniliprole towards larval stages of many important lepidopteran pests, it also exhibits mating disruption at sub-lethal doses, as demonstrated in the codling moth, *Cydia pomonella* (L.). Male insects exposed to the insecticide's residues exhibited significantly reduced activity leading to less number of successfully mated females (Knight and Flexner, 2007). The molecular target of chlorantraniliprole was described in detail by Cordova *et al.* (2006). Accordingly the dorsal vessel (heart) and skeletal muscles of *Manduca sexta* (L.) showed adverse contractility on exposure to diamides. Plasma membrane calcium channels were ruled out as a potential diamide target by analysis of the change in intracellular Ca²⁺ concentrations in *Periplaneta americana* (L.) neuron preparations in calcium-free conditions during exposure to anthranilamides. The RyRs were identified as the actual target by calcium release imaging done on Sf9 cells expressing *D. melanogaster* RyRs and by radiolabeled ryanodine and diamide binding studies on *P. americana* leg muscle membrane preparations (Lahm *et al.*, 2007).

Cyantraniliprole belongs to the same family of compounds as chlorantraniliprole, but its insecticidal activity is much broader, affecting both chewing and sucking pests from the orders Coleoptera, Lepidoptera and Hemiptera (Legocki *et al.*, 2008). Its modified structure improves its mobility through the plant xylem, so it can be applied as a systemic insecticide (Jeanguenat, 2013; Foster *et al.*, 2012). Both chlorantraniliprole and cyantraniliprole bind to a site on the RyRs distinct from the binding site for ryanodine and their presence increases the likelihood of ryanodine binding (Isaacs *et al.*, 2012).

2.2. Bioefficacy

2.2.1. Tomato

2.2.1.1. Management of tomato fruit borer, *Helicoverpa armigera* Hubner with other insecticides

Several insecticides have shown great promise in controlling tomato fruit borer. A partial list of new chemistries includes profenofos 50 EC @ 1.5 l ha⁻¹ (Rana *et al.*, 2002; Sivakumar *et al.*, 2003), emamectin benzoate 5 SG @ 10 and 8.75 g a.i. ha⁻¹ (Suganya Kanna *et al.*, 2005; Murugaraj *et al.*, 2006), profenofos 50 EC @ 400 and 600 g a.i. ha⁻¹ (Sarangdevot *et al.*, 2006), indoxacarb 15 SC @ 50, 60 and 75 g a.i. ha⁻¹ (Shivalingasamy *et al.*, 2008), spinosad 45 SC (@ 75 g a.i. ha⁻¹ (Ravi *et al.*, 2008) and spinosad 45 SC (@ 73 and 84 g a.i. (Ghosh *et al.*, 2010).

2.2.1.2. Management of serpentine leafminer *Liriomyza trifolii* (Burgess) with other insecticides

In tomato, field studies carried out in Tamil Nadu, India, showed that abamectin (Abamectin 1.8 EC) @ 20 g a.i. ha⁻¹ twice at 20 days interval significantly reduced the damage caused by *L. trifolii* and increased the yield (Logiswaran and Bhuvanewari, 2000). Similarly, abamectin @ 10.0 g a.i. ha⁻¹ in Namdhari Hybrid-815 recorded the lowest percentage of damaged leaflets (17.78%) and highest yield (150.00 q ha⁻¹) followed by abamectin @ 7.0 g a.i. ha⁻¹ with yields of 138.78 q ha⁻¹ (Walunj *et al.*, 2002). Abamectin, metaflumizone, chlorantraniliprole, indoxacarb, spinetoram, novaluran, flubendiamide and pyridalyl evaluated against serpentine leafminer indicated that abamectin and spinetoram gave significant reduction in mines (Dakshina *et al.*, 2007).

2.2.2. Rice

2.2.2.1. Management of leaf folder, *Cnaphalocrocis medinalis* Guenee with chemical insecticides

Rice leaf folder has been reported from all rice growing areas which causes economic damage particularly at the vegetative stage of the crop. The larvae injure leaves by scrapping, folding and webbing leading to 60 per cent loss (Verma *et al.*, 1979). Triazophos effectively controlled the leaf folder incidence and synthetic pyrethroids recorded 10 - 25 per cent leaf damage (Nadarajan and Skaria, 1988). Phosphamidon, quinalphos and monocrotophos had complete egg mortality followed by fenthion (96%). Endosulfan exhibited the least ovicidal action (21.00 %) as compared to 11.00 per cent in control (Raju *et al.*, 1988). Phosphamidon 85 WSC, quinalphos 25 EC and monocrotophos 36 WSC were on par with in 88.90 per cent mortality of eggs followed by fenthion (88.40 %). Among pyrethroids, cypermethrin (91.10 %) was the most effective followed by fenvalerate (90.50 %), deltamethrin (90.20 %) and permethrin (90.20 %) that were on par with each other (Raju *et al.*, 1990). Profenofos and chlorpyrifos @ 500 g a.i. ha⁻¹ were the most effective treatments in reducing the leaf folder damage and increased grain yield over untreated check by 32.30 and 46.90 per cent, respectively (Singh and Singh, 1999). For the control of this pest in Asia, more than 25 per cent of applied pesticides are aimed to this pest in a year (Heong and Escalanda, 1997). Karthikeyan and Purushothaman (2000) reported that profenofos at 375 g a.i. ha⁻¹ recorded significantly lesser leaf folder damage (0.35 and 2.97 at 27 and 57 DAT, respectively). Verma and Gupta (2001) reported that quinalphos 25 EC and monocrotophos 36 WSC effectively reduced the population of leaf folder up to 88.17 and 87.44 per cent respectively and consequently increased yield of rice 17.92 and 16.24 q ha⁻¹, respectively at 250 ml ha⁻¹ compared to untreated control.

Lambda cyhalothrin was found to be effective based on reduced leaf damage and increased yield at 250 g a.i. ha⁻¹ (Rao *et al.*, 2002). Panda *et al.* (2004) have noted that fipronil 0.4 G performs well in field condition. Three doses of fipronil 80 WG *i.e.* 37.5, 50.0 and 62.5 g. ha⁻¹ (30, 40 and 50 g a.i. ha⁻¹) were evaluated against stem borer and leaf folder on basmati rice and all the three doses were on par with each other and showed

less leaf folder infestation (0.52 - 0.61 % leaf folder damage) (Mahal *et al.*, 2008). Benfuracarb 3G @ 1500-2000 g a.i. ha⁻¹ gave satisfactory control of rice pest complex along with significant increase in yield (Dhar *et al.*, 2009). Kaushik and Deb (2011) observed that monocrotophos and cypermethrin gave good control of rice leaf folder and were at par statistically.

2.2.2.2. Management of yellow stem borer, *Scirpophaga incertulas* Walker with chemical insecticides

The larva feeds inside the stem causing drying of central shoot or dead heart in young plants and drying of panicle or white ear in older plants (David and Kumaraswami, 1996). From a large dataset in India obtained from 28 years of experiments, one per cent dead heart caused 2.50 per cent yield loss, one per cent white heads cause four per cent yield loss, and one per cent dead heart and whitehead caused 6.40 per cent yield loss (Muralidharan and Pasalu, 2006).

Dhaliwal and Jaswant Singh (1986) found that the sprays phosphamidon 85 WSC, monocrotophos 36 WSC and chlorpyrifos 20 EC @ 0.5 kg a.i. ha⁻¹ provided effective control against stem borer. Pandya *et al.* (1987a) revealed that aqueous 0.04 per cent solution of monocrotophos 36 WSC was the most effective in killing neonate larvae of YSB (yellow stem borer) (68.90 %) followed by fenitrothion 50 EC (65.90 %) and chlorpyrifos 20 EC (63.10 %). Monocrotophos 36 WSC @ 0.004 per cent aqueous solution was highly ovicidal with 63.20 per cent unhatched eggs followed by chlorpyrifos 20 EC (61.70 %) and methyl parathion 50 EC (60.30 %) on the eggs of *S. incertulas* (Pandya *et al.*, 1987b).

Sukhija *et al.* (1988) found that among granular insecticides, cartap hydrochloride was the most effective with 3.8 per cent white ear. Application of carbofuran 3G @ 1 kg a.i. ha⁻¹ followed by monocrotophos 0.5 kg a.i. ha⁻¹ gave effective protection against YSB and recorded minimum incidence of 2.35 to 4.13 per cent dead heart than all other treatments tested (Singh, 1996). Singh and Sarao (2000) found that lambda cyhalothrin at 12.5 g a.i. ha⁻¹ was more promising with 13.68 per cent white ear damage and 4750 kg ha⁻¹ grain yield. According to Jena (2001) seedling root dip with 0.02 per cent emulsion of chlorpyrifos was effective in controlling YSB infestation at initial stages of the crop

and was superior to carbosulfan 1000 g a.i. ha⁻¹ at both vegetative and grain filling stages. Baruah *et al.* (2008) recorded that carbosulfan 20 EC @ 350 g a.i. ha⁻¹ showed the lowest over all increase of stem borer infestation (1.43 and 2.79 %) in 2005 and 2006 when compared to the untreated check (7.79 and 11.61 %). At 75 DAS fipronil 0.3G @ 7.5 g a.i. ha⁻¹ was superior with lowest per cent dead heart of 2.43 (Hugar *et al.*, 2009). Experiments conducted by Rajesh (2013) revealed that carbosulfan 25 EC @ 300 and 250 g a.i. ha⁻¹ reduced the stem borer damage to the extent of 50.07 and 48.78 per cent, respectively.

2.2.3. Bioefficacy of anthranilic diamide insecticides against insect pests

Flubendiamide as granular as well as liquid formulations were tested against many of the agricultural pests.

2.2.3.1. Rice

Flubendiamide 20 WDG @ 25 and 50 g a.i. ha⁻¹ recorded low level of dead heart (0.81 and 0.53%) and white ear (1.26 and 1.24%) compared to other treatments and @ 12.5, 25 and 50 g a.i. ha⁻¹ was found effective in reducing the leaf folder damage and stem borer at all the doses tested (Javaregowda and Naik, 2005). Two field experiments conducted by Thilagam (2006) at Coimbatore revealed that the application of flubendiamide 480 SC @ 30 g a.i. ha⁻¹ was effective against rice leaf folder (LF) and stem borer (SB) in rice by reducing the damage by 85.15 and 88.92 per cent, respectively. Flubendiamide 20 WG @ 25 g a.i. ha⁻¹ controlled stem borer, *Chilo suppressalis* (Walk.) and leaf folder, *C. medinalis* on rice (Hirooka *et al.*, 2007). Flubendiamide 480 SC @ 24 and 30 g a.i. ha⁻¹ when applied twice at 30 and 45 DAT exerted effective control of leaf folder damage to 1.66 and 0.97 scale, respectively compared to the damage in the control showing 7.34 scale out of 9.0 scale rating during 2003 at Burdwan, West Bengal (Sekh *et al.*, 2007). Field experiments conducted on rice (Misra, 2008) at Bhubaneswar, Odisha revealed that the leaf folder damage was significantly reduced by 53.33 per cent over control with flubendiamide 20 WG @ 35 g a.i. ha⁻¹.

Bhanu and Reddy (2008) and Mallikarjunappa *et al.* (2008) testified that flubendiamide 20 WG @ 35 g a.i. ha⁻¹ was the most effective in reducing the incidence of rice stem borer and leaf folder. Application of the combined product flubendiamide 35 g

+ hexaconazole 50 g @ 2 g l⁻¹ on rice effectively reduced the yellow stem borer (YSB) infestation to 6.6 from 17.70 per cent white ear with increased grain yield of 3875 kg ha⁻¹ compared to untreated plots (1050 kg ha⁻¹) (Biswas, 2012). Flubendiamide 480 SC @ 0.2 ml l⁻¹ was proved to be highly effective against rice leaf folder which was on par with spinosad, indoxacarb and fipronil (Suresh *et al.*, 2011).

Hardke *et al.* (2011) recorded that chlorantraniliprole, cyantraniliprole and flubendiamide reduced fall armyworm infestations by >2.5-fold than control. The newer insecticides displayed efficacy equal to or greater than standard insecticides *viz.*, indoxacarb, lambda-cyhalothrin, methoxyfenozide, novaluron and spinosad (Baldwin *et al.*, 2010; Catchot, 2010; Studebaker, 2010). Single soil application of Virtako[®] 1.5 G (chlorantraniliprole 5% + thiamethoxam 10%) @ 6 kg ha⁻¹ at 30 days after transplanting during 2012-13 recorded 4.09 per cent leaf damage, 4.12 per cent dead heart and 2.21 per cent white ear as compared to untreated control (25.53 per cent leaf damage, 34.42 per cent dead heart and 25.54 per cent white ear) (Murali Baskaran *et al.*, 2013).

2.2.3.2. Pulses

The lowest pod damage of 9.98 per cent in blackgram was recorded with flubendiamide 480 SC @ 48 g a.i. ha⁻¹ (Patil *et al.*, 2008). Studies carried out by Deshmukh *et al.* (2010) revealed that flubendiamide (0.007%), indoxacarb (0.0075%), spinosad (0.009%) and emamectin benzoate (0.0015%) were the most effective in reducing the pod damage by *H. armigera* in chickpea. Flubendiamide 480 SC @ 100 ml ha⁻¹ caused significant reduction in *H. armigera* and *Maruca testulalis* (L.) larvae and recorded minimum flower and pod damage (Ameta *et al.*, 2011).

Flubendiamide 24 + thiacloprid 48 SC recorded comparatively higher *Maruca* larval reduction in blackgram (76.56 and 84.45 %) in first and second spray, respectively (Shivaraju *et al.*, 2011). Flubendiamide 480 SC @ 0.01 per cent recorded the highest reduction in *H. armigera* larval population (97.02 %), pod damage at green pod stage (90.24%) and maturity stage (87.96 %) and increase in yield over control (92.31 %) in chickpea (Babar *et al.*, 2012). Manu *et al.* (2014) observed that, flubendiamide 480 SC @ 0.2 ml l⁻¹ was superior in reducing the leaf eating caterpillar, *Spodoptera litura* (Fab.) population up to 95.84 per cent after two rounds of spraying in soybean.

Mahalakshmi *et al.* (2013) observed that the mean larval incidence in blackgram after two sprays revealed that the lowest larval count of 0.69 larvae m⁻¹ was recorded with chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ followed by chlorantraniliprole @ 25 g a.i. ha⁻¹ (0.89 larvae m⁻¹) and chlorantraniliprole at 20 g a.i. ha⁻¹ (1.07 larvae m⁻¹). The pod damage by *Maruca vitrata* Fabricius was 4.52 per cent with chlorantraniliprole @ 30 g a.i. ha⁻¹ followed by chlorantraniliprole @ 25 and 20 g a.i. ha⁻¹ (7.69 and 9.58 %, respectively). Meena *et al.* (2014) recorded the lowest *S. litura* larval population (0.11 and 0.0, respectively per sq. m. row) with chlorantraniliprole 18.5 SC @ 30 g a.i. ha⁻¹ at 5 and 10 days after second spraying.

2.2.3.3. Cotton

Thilagam (2006) reported that flubendiamide 480 SC @ 60 g a.i. ha⁻¹ was highly effective against bollworm complex in cotton *viz.*, *H. armigera* and *Pectinophora gossypiella* (Saund.). The results of the experiments conducted by Lakshminarayana and Rajashri (2006) and Hirooka *et al.* (2007) revealed that flubendiamide 20 WG @ 50 g a.i. ha⁻¹ was effective in minimizing the boll damage caused by *H. armigera*. Flubendiamide 480 SC @ 60 g a.i. ha⁻¹ decreased bollworm incidence with higher seed cotton yield (Udikeri *et al.*, 2008). Bheemanna *et al.* (2010) testified that flubendiamide 20 WG @ 100 g a.i. ha⁻¹ recorded the lowest bollworm incidence (8.82 and 5.84%) during 2008-09 and 2009-10.

Mean data over two years revealed that chlorantraniliprole @ 40 g a.i. ha⁻¹ and spinosad @ 75 g a.i. ha⁻¹ recorded the lowest square damage and reduced boll damage inflicted by *H. armigera* (Bachelor and Mott, 2007; Hardke *et al.*, 2008; Prasad and Rao, 2010). Cyantraniliprole @ 105 and 90 g a.i. ha⁻¹ recorded higher per cent larval mortality than the rest of treatments. Chlorantraniliprole demonstrated better control against three major pests of cotton, *H. virescens*, *Helicoverpa zea* (Boddie) and *Spodoptera frugiperda* (Smith) (Temple *et al.*, 2009; Lahm *et al.*, 2007). Dhawan *et al.* (2009) stated that chlorantraniliprole @ 30 g a.i. ha⁻¹ resulted in significantly the lowest floral shedding, boll damage and locule damage as compared to the standard checks and recorded the highest seed cotton yield without any resurgence in sucking pests.

2.2.3.4. Horticultural crops

Application of chlorantraniliprole 20 SC @ 50 g a.i. ha⁻¹ as foliar spray achieved, cent per cent mortality of *H. zea* 18 days after spraying compared to 77.00, 70.00 and 13.00 per cent mortality with methoxyfenozide (135 g a.i. ha⁻¹), fenvalerate (56 g a.i. ha⁻¹) and spinosad (75 g a.i. ha⁻¹), respectively (Anonymous, 2007). Flubendiamide 480 SC @ 48 g a.i. ha⁻¹ recorded the lowest population of *H. armigera* in tomato (Kuttalam *et al.*, 2008). Chatterjee and Mondal (2012) observed that, flubendiamide 20 WG effectively reduced the mean fruit damage (3.52 %) which was reflected on the highest yield (81.55 q ha⁻¹) in tomato. Mandal (2012) reported that cyantraniliprole 10 OD @ 90 and 105 g a.i. ha⁻¹ was highly effective in controlling the fruit borer, *H. armigera* and increased the yield of marketable fruits and also @ 60 to 105 g a.i. ha⁻¹ effectively controlled the leafminer, *L. trifolii* and cyantraniliprole 10 OD @ 90 g a.i. ha⁻¹ might be recommended for the control of pests in tomato (Mandal, 2012). Similarly, cyantraniliprole (HGW86) 10 OD @ 90 and 105 g a.i. ha⁻¹ recorded the lowest number of serpentine leafminer (SLM) adults 5 plants⁻¹ (0.66-0.74 in 2009–10 and 0.77-0.85 in 2010–11) at 7 days after spraying (DAS). The lowest number of SLM pupae was also observed in the plots treated with cyantraniliprole (HGW 86) 10 OD @ 90 and 105 g a.i. ha⁻¹ both during 2009-10 (1.15-1.33) and 2010-11 (1.10-1.25), compared to untreated control (Misra, 2013). Jat and Ameta (2013) reported that flubendiamide 480 SC @ 200 ml ha⁻¹ was significantly effective, with the highest mean reduction of tomato fruit borer larvae and fruit damage (89.94 and 3.10 %, respectively). Larrain *et al.* (2014) reported that foliar application trials in both seasons showed that doses between 400 and 1000 ml ha⁻¹ of cyantraniliprole 10 OD were highly effective in controlling tomato moth, *Tuta absoluta* Meyrick and decreased foliage and fruit damage

Latif *et al.* (2009) observed the lowest per cent of fruit and shoot damage in the brinjal plot sprayed with flubendiamide 20 WG (0.012%). Latif *et al.* (2010) reported that flubendiamide 24 WG showed the highest toxicity against *Leucinodes orbonalis* (Guenee) larvae after 24 and 48 h of exposure under laboratory condition. Studies carried out by Rajavel *et al.* (2011) revealed that chlorantraniliprole @ 60 g a.i. ha⁻¹ recorded the lowest mean fruit damage of 4.99 per cent followed by 50 g a.i. ha⁻¹ (5.43%) and 40 g a.i. ha⁻¹ (5.70%) in brinjal.

Chlorantraniliprole @ 40-60 g a.i. ha⁻¹ significantly reduced brinjal shoot and fruit borer *L. orbonalis* infestation (Mandal *et al.*, 2011). Similar results with chlorantraniliprole @ 40 and 50 g a.i. ha⁻¹ resulted in 95.00 and 97.00 per cent reduction in shoot damage and 87.00 and 90.00 per cent reduction in fruit damage, respectively at 10 days after fourth spray (Misra, 2011).

Flubendiamide 480 SC @ 50 ml ha⁻¹ significantly reduced the *P. xylostella* population and recorded higher yield in cabbage (Ameta and Bunker, 2007). Similarly, flubendiamide 480 SC @ 48 g a.i. ha⁻¹ recorded the lowest population of *P. xylostella* (Vinothkumar *et al.*, 2007). Flubendiamide 20 WG @ 25 and 50 g a.i. ha⁻¹ was effective against *P. xylostella* which is normally resistant to conventional insecticides *viz.*, spinosad, indoxacarb and fipronil at recommended doses in Thailand. Flubendiamide achieved an efficacy equivalent to that of chlorfenapyr and it was superior to spinosad @ 25 g a.i. ha⁻¹ in Malaysia (Hirooka *et al.*, 2007).

Tatagar *et al.* (2009) tested flubendiamide 20 WG against chilli fruit borers (*H. armigera* and *S.litura*) and the results indicated that, flubendiamide 20 WG @ 60 g a.i. ha⁻¹ recorded the highest yield of 7.48 q ha⁻¹ with the lowest fruit damage (3.45%). Sreenivas *et al.* (2011) reported that flubendiamide 480 SC @ 48 g a.i. ha⁻¹ in chilli effectively reduced *S. litura* to 0.47 larvae row⁻¹ and *H. armigera* to 0.40 larvae plant⁻¹ at 10 days after spray and recorded the highest fruit yield (25.12 q ha⁻¹). Patel *et al.* (2012) described that cyantraniliprole 10 OD @ 70, 60 and 50 g a.i. ha⁻¹ found significantly effective in preventing the per cent fruit damage by *H. armigera* in chilli.

According to Rajesh Chowdary *et al.* (2010b) chlorantraniliprole 20 SC @ 30 and 20 g a.i. ha⁻¹ was superior in recording less *H. armigera* larval populations and lower fruit damage in okra.

Dhaka *et al.* (2011) reported that flubendiamide 39.35 EC @ 75 ml ha⁻¹ was the best with the lowest pod and seed infestation of 11.37 and 12.98 per cent, respectively and 95.84 q ha⁻¹ yield against *Etiella zinckenella* (Treitschke) in vegetable pea.

Chlorantraniliprole 20 SC @ 125, 175 and 2 ml ha⁻¹ strongly reduced (83.00-100.00 %) the number of codling worms of fruits during harvests in apple

(Milanesi *et al.*, 2008; Sumedrea *et al.*, 2009). Yadav *et al.* (2012) reported that cyantraniliprole @ 70 and 80 g a.i. ha⁻¹ was the most effective in reducing *S. litura* population in grapes.

2.2.4. Yield

Javaregowda and Naik (2005) recorded the highest rice yield with flubendiamide 20 WG @ 50 g a.i. ha⁻¹. The highest yield was recorded in rice plots treated with flubendiamide @ 50 g a.i. ha⁻¹ (6230 kg ha⁻¹) (Gowda, 2005). According to Thilagam (2006), the highest rice grain yield was realized in flubendiamide 480 SC treated plots in two seasons. Flubendiamide 20 WG @ 35 g a.i. ha⁻¹ recorded the highest grain yield in rice (Mallikarjunappa *et al.*, 2008). Tamboli and Lolage (2008) recorded higher grain yield @ 1565 kg ha⁻¹ in rice treated with flubendiamide 20 WG @ 50 g a.i. ha⁻¹. Murali Baskaran *et al.* (2013) reported that the single soil application of Virtako® (chlorantraniliprole 20 % + thiamethoxam 20 %) 1.5 G @ 6 kg ha⁻¹ at 30 days after transplanting during 2012-13 recorded the highest rice grain yield of 5.61 t ha⁻¹ as compared to untreated control (2.88 t ha⁻¹).

Meena *et al.* (2006) reported that flubendiamide 20 WG @ 50 g a.i. ha⁻¹ recorded the highest grain yield in pigeonpea. Patil *et al.* (2008) reported the highest yield in flubendiamide 480 SC @ 48 g a.i. ha⁻¹ in blackgram. The highest grain yield was obtained in the plots treated with flubendiamide 20 WG @ 70 g a.i. ha⁻¹ in blackgram and flubendiamide at 50 g a.i. ha⁻¹ in bengalgram (Lincy, 2013). Manu *et al.* (2014) reported that among the new molecules, flubendiamide 480 SC @ 0.2 ml l⁻¹ recorded the highest seed yield (23.95 q ha⁻¹) followed by indoxacarb 14.5 SC (22.99 q ha⁻¹) and lambda cyhalothrin 5 EC (22.87 q ha⁻¹) in soybean.

Lakshminarayana and Rajashri (2006) stated that flubendiamide @ 100 g a.i. ha⁻¹ recorded higher seed cotton yield (1946 kg ha⁻¹) compared to standard checks (spinosad and indoxacarb).

Ghosal *et al.* (2012) reported that in tomato chlorantraniliprole 18.5 SC @ 40 g a.i. ha⁻¹ was superior over other treatments against *H. armigera*, with 98.04 per cent reduction, followed by flubendiamide 20 WG @ 30 g a.i. ha⁻¹ (87.96%) and chlorantraniliprole 18.5 SC @ 20 g a.i. ha⁻¹ (85.84%). The mean marketable tomato yield

was significantly higher in treatments cyantraniliprole (HGW 86) 10 OD @ 90 and 105 g a.i. ha⁻¹ (16.26-16.65 t ha⁻¹) with an increase of 48.90-52.49 per cent over untreated control (Misra, 2013).

Rajavel *et al.* (2011) recorded higher brinjal yield in chlorantraniliprole @ 60 g a.i. ha⁻¹ treated plot (13.22 t ha⁻¹) followed by chlorantraniliprole 20 SC @ 50 g a.i. ha⁻¹ (12.73 t ha⁻¹) and 40 g a.i. ha⁻¹ (12.49 t ha⁻¹).

Ameta and Kumar (2008) reported the higher marketable yield in chilli with flubendiamide 480 SC @ 60 g a.i. ha⁻¹ (125 t ha⁻¹). Similarly Tatagar *et al.* (2009) recorded the higher fruit yield in chilli with flubendiamide 20 WG @ 60 g a.i. ha⁻¹ and the higher fruit yield in tomato by Chatterjee and Mondal (2012). Cyantraniliprole 10 OD @ 60 and 70 g a.i. ha⁻¹ recorded higher green chilli fruit yield of 137.12 and 125.28 q ha⁻¹, respectively followed by cyantraniliprole @ 50 g a.i. ha⁻¹ (97.94 q ha⁻¹) (Patel *et al.*, 2012).

Ameta and Bunker (2007) recorded the highest marketable yield of cabbage when flubendiamide 480 SC was sprayed @ 24 g a.i. ha⁻¹ followed by its lower dose @ 18 g a.i. ha⁻¹ on cabbage plants.

2.3. Phytotoxicity

The foliar application of flubendiamide 480 SC did not cause any phytotoxic symptoms even at two (96 g a.i. ha⁻¹) and four times (192 g a.i. ha⁻¹) the recommended dose (48 g a.i. ha⁻¹) on cotton variety Ajit 11. Similarly, flubendiamide 480 SC did not cause any phytotoxic symptoms @ 24, 48 and 96 g a.i. ha⁻¹ on rice variety ADT 43 (Thilagam, 2006). No phytotoxic symptoms was observed with flubendiamide 20 WG on cotton plants even at higher dose @ 100 g a.i. ha⁻¹ (Lakshminarayana and Rajashri, 2006).

Flubendiamide was tested for crop safety on different plant species (cabbage, Chinese cabbage, lettuce, Japanese radish, strawberry, tomato, green onion, soybean, apple, pear, peach and tea) under greenhouse conditions. The compound showed no phytotoxicity even at the highest concentration of 400 mg l⁻¹ (Hirooka *et al.*, 2007). The field experiment conducted during 2006 - 2007 at Udaipur on cabbage showed that

application of flubendiamide @ 50, 100 and 200 ml ha⁻¹ did not cause any phytotoxicity symptoms during the experimental period (Ameta and Bunker, 2007).

Flubendiamide 480 SC @ 100, 200 and 400 ml ha⁻¹ was nil in tomato plants (Kubendran *et al.*, 2008a). Vinothkumar *et al.* (2010) also registered that, tomato plants sprayed with flubendiamide + thiacloprid 480 SC^{RM} @ 96, 192 and 384 g a.i. ha⁻¹ did not show any phytotoxicity. Lavanya (2013) reported that, flubendiamide 0.7 G either at recommended dose @ 100 g a.i. ha⁻¹ or double and quadruple or sub recommended doses did not cause any deleterious effect on rice. Lincy (2013) also proved that, flubendiamide 20 WG even at a higher doses (@ 240 and 200 g a.i. ha⁻¹) did not inflict any phytotoxicity symptoms on blackgram and chickpea, respectively.

Chlorantraniliprole 20 SC did not cause any phytotoxic symptoms in brinjal crop even at higher dosage @ 300 g a.i. ha⁻¹ (Mandal *et al.*, 2011). Mandal (2012) reported that cyantraniliprole 10 OD @ 360 g a.i. ha⁻¹ was safe to the brinjal crop.

2.4. Safety of insecticides to natural enemies

2.4.1. Insect parasitoids

According to Thilagam (2006), treatment with flubendiamide 480 SC did not show any ovipositional deterrence to *Trichogramma chilonis* (Ishii), which recorded more than 75 per cent parasitism. Similarly, treatment of parasitized eggs with flubendiamide did not show any ill effect on the development of parasitoids.

Laboratory studies revealed that flubendiamide 480 SC @ 24 and 30 g a.i. ha⁻¹ was safe to egg parasitoids of rice stem borer and larval parasitoids of leaf folder. The per cent parasitisation in the flubendiamide 480 SC treated plots was close to those of the untreated plots (Sekh *et al.*, 2007). Flubendiamide @ 75 ml ha⁻¹ registered higher per cent parasitisation (81.90 %), per cent adult emergence (85.20 %) and lower mortality in *Chelonus blackburnii* (Cam.) (Kubendran *et al.*, 2008a), while @ 80 mg a.i. l⁻¹ was the most selective of all the tested insecticides for the development, survival and fecundity on the different life stages of *T. chilonis* than lufenuron, indoxacarb, spinosad and emamectin benzoate (Shahid *et al.*, 2011). The application of flubendiamide 480 SC

@ 432 ml ha⁻¹ showed minimum effect on the emergence of *T. chilonis* and found to be safe (Dilbar *et al.*, 2012a).

Chlorantraniliprole has been reported to have an excellent environmental profile with low impact on fish, birds, mammals and demonstrated little or no toxicity to common beneficial arthropod species *viz.*, Chrysopidae, Coccinellidae, Nabidae, Lygaeidae and Braconidae (Anonymous, 2007). In rice ecosystem, imidacloprid, thiamethoxam, chlorantraniliprole, clothianidin, pymetrozine, ethofenprox, fenobucarb, endosulfan, acephate and the product Virtako[®] (chlorantraniliprole 20% + thiamethoxam 20 %) tested to determine their toxicity to the parasitoid, *T. chilonis* indicated that only chlorantraniliprole was found to be harmless based on risk quotient (ratio between the field-recommended doses and the LC₅₀ of the beneficial) (Preetha *et al.*, 2009). Chlorantraniliprole at doses tested had negligible effects on numerous beneficial arthropod species *viz.*, *Typhlodromus pyri* Scheuten or the parasitic wasp, *Aphidius rhopalosiphii* De Stefani Perez (Axel *et al.*, 2009). Mandal (2012) found that @ 34 -105 g a.i. ha⁻¹ cyantraniliprole 10 OD (oil dispersion) did not reduce the population of natural enemies in tomato crop and also in the laboratory and cyantraniliprole 10 OD @ 60 - 90 g a.i. ha⁻¹ was also found to be safe for *Trichogramma pretiosum* Riley.

2.4.2. Predators

2.4.2.1. Green lacewing

Tohnishi *et al.* (2005) observed that, flubendiamide was safe against *Chrysoperla zastrowi sillemi* (Esbens-Petersen) larvae when treated with >100 mg a.i. l⁻¹ in artificial diet. Flubendiamide 20 WG was safe to lady bird beetle, green lacewing, non-target arthropods and spiders (Hirooka *et al.*, 2007). The highest hatchability of *C. carnea* eggs was reported at 75 and 100 ml ha⁻¹ of the flubendiamide 480 SC (Kubendran *et al.*, 2008b). Foliar application of flubendiamide 480 SC @ 50, 75 and 100 ml ha⁻¹, indoxacarb 14.5 SC @ 500 ml ha⁻¹ and spinosad @ 187.5 ml ha⁻¹ did not cause adverse effects on the population of grubs and adults of *Coccinella* spp. and *C. carnea* (Ameta *et al.*, 2011). Dilbar *et al.* (2012b) reported that, application of flubendiamide 480 SC @ 432 g a.i. ha⁻¹ proved to be comparatively safer with 8 to 16 per cent mortality of 1st larval stage of *C. carnea* at all intervals (3, 6, 12 and 24 hours) except 48 hours. Mandal (2012) reported

that cyantraniliprole 10 OD @ 45 - 105 g a.i. ha⁻¹ did not significantly reduce the field population of natural enemies and was safe to the crop even @ 360 g a.i. ha⁻¹.

2.4.2.2. Coccinellid predators

Rajavel *et al.* (2011) reported that population of coccinellids did not show any significant differences between chlorantraniliprole 20 SC treated plot and untreated plot which recorded a mean population in the range of 3.41 to 3.88 coccinellids plant⁻¹ in brinjal.

Mahalakshmi *et al.* (2013) observed that no significant differences on the population of *Coccinella* sp. and *Scymnus* sp. in pulses with chlorantraniliprole 20 SC @ 20, 25 and 30 g a.i. ha⁻¹. The predatory coccinellid numbers did not differ significantly from that of control during post application period which indicated the safety of cyantraniliprole @ 90 and 105 g a.i. ha⁻¹ tested in tomato (Misra, 2013).

2.4.2.3. Spiders

Present agricultural practices in general, exposure and susceptibility will determine the risk of an organism to suffer from side effects of pesticides (Jepson, 1989). High susceptibility to pesticide is typical to spiders (Basedow *et al.*, 1985; Everts, 1990). Spiders live in the vegetation layer and are active during and after spraying and they are easily exposed to pesticides (Jepson, 1989). Furthermore, their webs are excellent collectors of pesticide spray (Samu *et al.*, 1992) and sub-lethal doses can change or temporarily prevent the web building behaviour of spiders (Samu and Vollarath, 1992). Linyphiidae was the most sensitive indicators of pesticide side effects in temperate arable crops (Everts, 1990; Everts *et al.*, 1991). Although pesticides may not necessarily always be lethal, sub-lethal effects may cause dramatic changes in walking speed, selecting suitable habitat conditions and preventing predation (Everts *et al.*, 1991). Many authors have reported short-term effects of pesticides on spiders. Population depletion of 50 to 90 per cent had been shown to persist between years in groups of fields receiving high pesticide inputs (Burn, 1992; Vickerman, 1992). The adverse effects of pesticides on spiders are well documented both in laboratory and field conditions (Stark *et al.*, 1995). Field experiments have shown that insecticide sprays disorganised predator-prey relationship, food chain linkages (Cohen *et al.*, 1994), destroyed natural enemies and detritivores (Heinrichs, 1994; Settle *et al.*, 1996). However, Dakshina *et al.* (2007) reported among the insecticide treatments *viz.*, metaflumizone, indoxacarb,

novaluron, spinetoram and spinosad, spider population was fully revived in treatment such as metaflumizone, indoxacarb and spinosad at 7 DAT.

Javaregowda and Naik (2005) reported that the toxicity level of flubendiamide at 12.5, 25 and 50 g a.i. ha⁻¹ on predatory spiders and mirid bugs in rice ecosystem was statistically on par and safer than chlorpyrifos and lambda cyhalothrin. Tohnishi *et al.* (2005) observed that, flubendiamide was inactive against adults of *Pardosa pseudoannulata* (Boesenberg and Strand) and *Misumenops tricuspidatus* (Fab.) in insect dipping method of bioassay. The level of toxicity of flubendiamide 480 SC to predaceous spiders, coccinellids and chrysopids in cotton and towards spiders, rove beetles and mirids in rice increased with increase in dose (Thilagam, 2006).

Chlorantraniliprole 20 SC @ 20 - 60 g a.i. ha⁻¹ dosages did not cause any significant reduction in the predatory fauna present in the egg plant ecosystem (Mandal *et al.*, 2011). Rajavel *et al.* (2011) reported that population of spiders did not show any significant difference between chlorantraniliprole 20 SC treated plot and untreated plot which recorded a mean population in the range of 2.03 to 2.40 spiders plant⁻¹ in brinjal. Single soil application of Virtako® 1.5 G @ 6 kg ha⁻¹ 30 days after transplanting during 2012-13 recorded moderate level of population of mirids and spiders (Murali Baskaran *et al.*, 2013). Mahalakshmi *et al.* (2013) observed that there was no significant differences among the treatments regarding the incidence of spiders in pulses with chlorantraniliprole 20 SC @ 20, 25 and 30 g a.i. ha⁻¹.

2.4.2.4. Safety to pollinators and honeybees

Thilagam (2006) observed that, little bees were more affected due to the application of flubendiamide than Indian and Italian bees. Italian bee mortality was the lowest in flubendiamide @ 36 g a.i. ha⁻¹ (9.17%) followed by flubendiamide @ 48 g a.i. ha⁻¹ (14.57%) and 60 g a.i. ha⁻¹ (17.59%) 12 hours after treatment (HAT). The mortality increased as the time of exposure increased. Chlorantraniliprole 20 SC tested against honey bees showed low intrinsic toxicity to honey bees. The oral and contact LD₅₀ values were > 0.027 and > 0.005 µg chlorantraniliprole bee⁻¹ (Axel Dinter *et al.*, 2009). Gradish *et al.* (2012) reported that eggs and larvae collected from field and their pollen provisions

treated with flubendiamide (Belt® 480 SC) had no toxic effects to *Megachile rotundata* (Fab.) adults.

2.5. Compatibility with microbials

Fungal biological control agents and selective insecticides might act synergistically increasing the efficiency of the control, allowing the lower doses of insecticides, conservation of natural enemies, minimizing environmental pollution and decreasing the likelihood of development of resistance to either agent (Boman, 1980; Moino and Alves, 1998; Ambethar, 2009). Kumar (1998) reported that imidacloprid 200 SL had lesser impact on the growth of *Trichoderma viride* Persoon and exerted a pronounced effect on the growth of *Pseudomonas fluorescens* Migula. The results revealed that integration of carbendazim (0.1%) and *T. viride* mutant strain on seed with soil application of phosphorus at 20 kg ha⁻¹ and potassium @ 15 kg ha⁻¹ caused the highest (91.70 %) reduction in sesame stem and root rot incidence over control. Dohroo (2001) studied the effect of *Trichoderma harzianum* Rifai along with the chemicals Dithane M- 45 and Bavistin for the management of rhizome rot of ginger. The combined application of *T. harzianum* +Dithane M- 45 (0.25 %) + Bavistin (0.1 %) + *Trichoderma* soil application (250g 3m⁻²) recorded 38 per cent reduction in disease incidence and also increased the yield. Boucias *et al.* (1996) observed synergistic effects of imidacloprid with *Beauveria bassiana* (Bals) Vuill. on *Reticulitermes flavipes* Kollar and stated that imidacloprid interfered with the behavioural resistance. The use of *B. bassiana* along with imidacloprid or thiacloprid was effective in reducing the population of *B. tabaci* and prevented the resistance development to these insecticides (Alves *et al.*, 2001).

The colony radial growth and conidial production of *B. bassiana* and *Metarrhizium anisopliae* (Mets) Soro. were less affected by imidacloprid (Moino and Alves, 1998). Neves and Alves (2000) recorded the synergistic action of imidacloprid and *M. anisopliae* and also reported that sublethal concentrations of imidacloprid inhibited grooming behaviour and allowed conidia to germinate and penetrate the cuticle causing infection on *Cornitermes cumulans* (Kollar). Singh and Singh (2005) stated that the residues of imidacloprid were found for 90 days and had no significant effect on fungi and actinomycetes population upto 15 days and between 15 and 60 days with some adverse effects.

Singh *et al.* (1993) analysed the synergistic interaction between two bacterial isolates in the degradation of carbofuran and the related carbamates namely carbaryl, bendiocarb and carbosulfan. When the medium containing carbofuran was inoculated with

Pseudomonas sp., it showed no degradation of the compound. However, there was a synergistic increase in degradation of carbofuran when it was inoculated with both *Pseudomonas* sp. and *Arthrobacter* sp. This is due to rapid hydrolysis and subsequent release of carbon monoxide from the side chain. The use of *Bacillus thuringiensis* Berliner (Bt) in alternation with endosulfan or as tank mixtures with fenvalerate / endosulfan / quinalphos was suggested for effective control of bollworm in cotton (Butter *et al.*, 1995). Kulkarni *et al.* (1995) reported that Bt combined with monocrotophos and fenvalerate had synergistic relationship.

Purwar and Sachan (2005) reported that fungitoxic effect of insecticides *viz.*, endosulfan, imidacloprid, lufenuron, diflubenzuron, dimethoate and oxydemeton methyl on *B. bassiana* (MTCC 984 strain) and all the insecticides except oxydemeton methyl and imidacloprid showed significant deleterious effect on fungal growth. Ansari and Sharma (2005) reported that *Bacillus thuringiensis* Berliner was found to be compatible with lufenuron, thiamethoxam and methomyl except ethion and *B. bassiana* found to be compatible with all the chemicals tested.

2.6. Arthropod biodiversity in tomato and rice ecosystem

Arthropods are frequently used as ecological indicators as they represent more than 80 per cent of the global species richness. They fulfill essential roles in ecosystem such as pollination, soil structure and function, decomposition and nutrient recycling, natural enemies of pest species, prey for highly valued vertebrate, *etc.*, (Pettersson *et al.*, 1995). They have short generation times and respond quickly to ecological changes. Further, various arthropod taxa have been used to detect anthropogenic impact on ecosystems including agriculture and climate change (Parmesan, 1996; Buddle *et al.*, 2000).

2.6.a. Insecta

Class Insecta has always been regarded as the most speciose class in the Animal Kingdom (Ehrlich and Wilson, 1991; Samways, 1993; Myers *et al.*, 2000). This class also constitutes a substantial proportion of terrestrial species richness and biomass and plays a significant role in ecosystem functioning (McGeoch, 1998). Even so, known species diversity is only a small fraction of the total species diversity.

2.6.b. Arachnida

Spiders are the most familiar and ubiquitous obligate carnivores that feed on different types of prey in different cropping systems. Spiders are the most abundant predators of insects in terrestrial ecosystem (VanHook, 1971). In India, various aspects like importance of spiders in agriculture, taxonomic status, ecology, predator - prey interactions, toxicity of chemicals *etc.*, were studied by Palanichamy (1980), Rao *et al.* (1981), Gupta *et al.* (1986), Rajendran (1987), Nirmala (1990), Vijayalakshmi and Ahimaz (1993), Ganesh kumar and Velusamy (2000), Vanitha (2000) and Mathirajan (2001). In Tennessee, vegetable garden plots from which spiders had been removed had higher pest numbers than those in which spiders remained (Bishop and Riechert, 1990).

Spiders are exceptional among the other taxa for their complete dependence on predation as a trophic strategy (Mitter *et al.*, 1988). Around 22,400 valid species of spiders were estimated, in which 400 valid genera and about 15 families of living spiders were described up to the year 1939. A total of 4850 additional species were described between 1948 and 1958. In the global scene, United States of America leads the world on studies of Aranea, both on systematics as well as on applied research (Chamberlin and Ivie, 1945; Forster, 1967). The notable contributors were Kaston (1978), Roth (1985), Platnick (1989), Levi (1981, 1983 and 1991) and Coddington *et al.* (1990). Tikader (1987) concentrated on spider studies in the Indian subcontinent. About 80 families of spiders were recorded from all over the world, among which, 43 families were reported in India. Memah *et al.* (2014) recorded Lycosidae (54 individuals), Araneidae (51) and Theridiidae (29) as the most abundance spiders found in tomato ecosystem.

2.6.1. Arthropods in tomato

Hummel *et al.* (2002) studied the effects of vegetable production system on arthropod populations and they collected ground beetles (Coleoptera: Carabidae), rove beetles (Coleoptera: Staphylinidae) and wolf spiders (Araneidae: Lycosidae) using pitfall traps (48 hour sampling period) at an interval of 25 days. They also found that carabids (*Harpalus* spp. and *Amara* spp) and lycosids were more active in ground level and these carabids were not affected by insecticide input, but lycosids were found to be lower in

plots treated with conventional insecticides. Alomar *et al.* (2002) reported *Dicyphus tamaninii* Wagner and *Macrolophus caliginosus* Wagner colonized in tomato fields 6-8 weeks after seedling transplantation.

Nalini (2006) reported that the tomato cropping system mostly composed of several predators and parasitoids. The predators include coccinellids *viz.*, *Menochilus sexmaculata* (F.), *Coccinella transversalis* (Fab.) and *Coccinella repanda* (Th.), predatory mirid bugs (Hemiptera), hymenopteran parasitoids, *Rhogas aligharensis* (Quadri.), *Bracon hebetor* (Say.) and spiders *viz.*, *Tetragnatha* sp. and *Oxyopes* sp. Most of the hymenopteran parasitoids and predators have short mouthparts and fulfil their energy requirements by feeding on relatively accessible sugar sources, such as exposed floral and extrafloral nectar (Jervis *et al.*, 1993; Wackers and Van Rijn, 2012). Conversely predatory mirid bugs such as *Dicyphus* spp. (Gillespie and McGregor, 2000; Gillespie *et al.*, 2012) and *Macrolophus* sp. (Perdikis and Lykouressis, 2004; Perdikis *et al.*, 2007; Portillo *et al.*, 2012) were zoophytophagous predators and were able to complete their development on tomato and other plants in the absence of prey. *Macrolophus pygmaeus* Rambur was also known to feed on pollen (Vandekerkhove and De Clercq, 2010) and extra-floral nectar (Portillo *et al.*, 2012).

Sharma and Bisen (2013) reported that a total of 56 insect species were recorded in vegetable ecosystem in a light trap collection. These belonged to eight orders and 34 families. Lepidoptera was the largest order with 23 species. Other orders were; Hemiptera (14 species), Coleoptera (11 species) and Orthoptera (4 species). Odonata, Hymenoptera, Isoptera and Dictyoptera were the other orders of minor significance. Among the other predatory orders, Odonata was represented by *Libellula* sp. (213) and *Coenagrion* sp. (48) belonging to family Libellulidae and Conenagriidae, respectively. Balzan and Moonen (2014) collected a total of 1663 arthropods from semi-natural vegetation in field margins of organic tomato by sweep netting. Several important natural enemy groups, such as predatory Miridae and Nabidae (Heteroptera), Parasitica (Hymenoptera), Coccinellidae (Coleoptera) and Thomisidae (Araneae) appeared to benefit from the presence of flowering strips.

2.6.2. Arthropods in rice

Arthropod pest and predator populations in rice fields are intimately associated with each other (Settle *et al.*, 1996). A lot of ecological research has been done on this and many scientific publications brought out on the occurrence, abundance and diversity of arthropods, besides the variations due to topography, geographical conditions and weather conditions (Landis *et al.*, 2000; Juen *et al.*, 2003). Suana *et al.* (2004) stated that the structure of the landscape, habitat type, period of plant growth also play a role in the diversity of the spider species. Sarwshri (2007) recorded 17 and 14 species by net sweeping. They belonged to three major orders (Homoptera, Hemiptera and Coleoptera) and five major families (Cicadellidae, Delphacidae, Alydidae, Pentatomidae and Chrysomelidae).

The work of Kenmore *et al.* (1984) and Heong *et al.* (1990 and 1992) indicated that relatively few of the large arrays of natural enemies, at least 188 species through its range (Khoo *et al.*, 1991), might be especially important in BPH control. When little or no insecticide is used, tropical irrigated rice fields possess a rich arthropod community including many different kinds of natural enemies (FAO, 1979) and in these circumstances, their species richness and abundance may sometimes be greater than those of pests (Heong *et al.*, 1991). The impetus for better understanding of the role of natural enemies stemmed from widespread and devastating outbreaks of *Nilaparvata lugens* Stal. associated with the early green revolution technology in tropical Asia (Way and Heong, 1994).

Agricultural Entomologists recorded the importance of spiders as a major factor in regulating pests and they have been considered as important predators of insect pests and serve as buffer to limit the initial exponential growth of prey population (Snyder and Wise, 1999; Nyffeler, 2000; Sigsgaard, 2000; Maloney *et al.*, 2003; Venturino *et al.*, 2008; Chatterjee *et al.*, 2009). Research showed that spiders in rice field can play an important role as predators in reducing planthoppers and leafhoppers (Chiu, 1979; Visarto Preap, 2001; Lu Zhong-Xian, 2006). Several workers reported the predatory potency of spiders in rice ecosystem (Samiyyan, 1996; Sahu *et al.*, 1996; Pathak and Saha, 1999; Bhattacharya, 2000; Sigsgaard, 2000; Vanitha, 2000; Mathirajan, 2001; Sunil Jose *et al.*, 2002; Satpathi, 2004; Sudhikumar *et al.*, 2005; Sebastian *et al.*, 2005; Motobayashi *et al.*, 2006). According to Bhatnagar *et al.* (1982) and Peter (1988), the

crop having more insects or insect visitors always had more spiders. Spiders are capable of reducing populations of herbivores that might not be limited by competition and food availability in some agroecosystems (Sunderland, 1999). Riechert and Lawrence (1997) reported that plots in an old field from which spiders had been removed had significantly higher herbivorous insect numbers than in those plots that contained spiders.

In Tamil Nadu, Rajendran (1987) reported five species of spiders from Coimbatore region. Subsequently surveys by Nirmala (1990) in Coimbatore, Bhavanisagar and Anamalai recorded 14 new species. Later, surveys by Anbalagan and Narayanaswamy (1999) in the eastern part of Tamil Nadu, revealed the presence of 21 species of spiders under 16 genera belonging to 10 families, whereas Ganesh kumar (1994) reported 17 species of spiders occurring in the rice field and border weeds of Coimbatore, 14 from Aliyarnagar and nine from Karaikal. Among the spiders reported from rice fields, *Lycosa pseudoannulata* (Boes and Stand) was the most predominant species in China (Shi *et al.*, 1991; Li Shaoshi, 1996), Japan (Chu and Okuma, 1970), Philippines (Mochida and Dyck, 1976), Korea (Kiritani *et al.*, 1972) and in India (Nirmala, 1990; Gubbaiah and Viraktamth, 1998). However, *Tetragnatha mandibulata* (Gravely) had also been reported as the dominant species in India (Chatterjee and Dutta, 1979) and in Bangladesh (Kamal *et al.*, 1992).

Sahu *et al.* (1996) reported that among the identified species, *L. pseudoannulata* was more prevalent followed by *Atypena formosana* (Oi), *Argiope catenulata* (Doleschall) and *Clubiona japonicola* (Boesenberg and Strand). The population of these four species also varied at different growth stages of rice. In the first 35 DAT of rice, *L. pseudoannulata* and *A. formosana* were considered as the important predators of green leafhopper (Sahu *et al.*, 1996; Mathirajan, 2001). Moreover *L. pseudoannulata* is the vital predator against brown planthopper and can also effectively regulate the pest population of leafhoppers, planthoppers, whorl maggot flies, leaf folders, case worms and stem borers (Kenmore *et al.*, 1984; Barrion and Litsinger, 1984; Shepard *et al.*, 1987; Rubia *et al.*, 1990; Ooi and Shepard, 1994; Visarto Preap, 2001; Drechsler and Settele, 2001; Lu Zhong-xian *et al.*, 2006). According to Mathirajan (2001) *Tetragnatha javana* (Thorell), was one of the common spiders found in rice ecosystem and they effectively reduced the population of green leafhoppers and brown planthoppers. In India, studies on the population and abundance of the spider assemblages in agricultural crops are few. Some basic studies

were carried out by Pathak and Saha (1999) and Bhattacharya (2000). Sahu *et al.* (1996) confers that, *L. pseudoannulata* preferred more *S. incertulas* and *C. medinalls. Acromantis formosana*(Shiraki) had a positive maximum correlation with pest *Leptocoris oratorius* (Fabricius). According to Bishop and Riechert (1990), the increase of spiders' density could decrease the pest density and pest damage. Thus spiders serve as buffer in the rice establishment techniques and limit the exponential growth of prey population in all the techniques.

Past research showed that spiders in rice fields are major components that act as predators in decreasing the plant hopper and leaf hopper densities (Holt *et al.*, 1987 and Tanaka, 1989). Irrespective of the spider species and their sexes, the prey preference of spider was in the order of *Nilaparvata lugens* (Stal) > *Sogatella furcifera* (Horvth) > *Nephotettix virescens* (Dist.) in rice (Nirmala, 1990). *L. pseudoannulata* preferred planthoppers to *N.virescens*, whereas *Oxyopes javanus* Thorell preferred *N. virescens* to plant hoppers (Ganesh Kumar, 1994).

2.6.3. Sampling methods of arthropods

Bishop and Riechert (1990) reported sweep net and visual counting methods for collecting spiders. Insects like ants and other ground crawling arthropods were commonly sampled by pitfall traps. The pitfall traps were the best means of collecting arthropods that were active on the soil surface (Kharboutli and Mack, 1993). Lewis *et al.* (1996) used sweep, shake and plant sampling methods to monitor the seasonal abundance of spiders along with other insects in cotton fields in Georgia. Pfiffner and Niggli (1996) reported that pitfall-trap was more effective in sampling spider, ground beetle and rove beetle population.

Easterbrook (1998) utilized the suction traps to determine the abundance of predators in strawberry fields along with the spiders. One interesting application of the pitfall traps might be to collect ant species as biological indicators (Peck *et al.*, 1998). Pitfall traps could yield species richness composition and relative abundance of foraging ants (Bestelmeyer *et al.*, 2000). Schmidt *et al.* (2005) studied the capture efficiency and preservation attributes between five guilds in a field experiment with special respect to spiders (Araneae) and ground beetles and finally concluded that the mixture of ethylene glycol and water combined as a good preservative with high capture efficiency.

2.6.4. Biodiversity indices

In order to accomplish goals of understanding or conserving nature, a biodiversity study requires substantial amounts of information used in estimating basic parameters. Some parameters of interest include, measures of species diversity, estimates of the types of biodiversity, estimates of changes in biodiversity and associated physical and biological factors. Managing such information admittedly is highly complex, but necessary in the study of biodiversity (Reaka Kudla *et al.*, 1997).

Measuring biodiversity provides the base line information on distribution, richness and relative abundance of the taxa that is needed for conservation decisions and studying ecosystem, ecology and cladistic biogeography (Whittaker, 1972). He defined three distinct levels of diversity which included alpha or within-habitat diversity, beta or between-habitat diversity (changes along environmental gradient) and gamma or large-scale landscape diversity (a composite of alpha and beta diversity). Ludwig and Reynolds (1988) reported that complete counts of organisms were impractical and hence, indirect solutions are needed that are practical, rapid and inexpensive.

2.6.5. Impact of insecticides on arthropod diversity

Conventional chemical insecticides such as organophosphates, carbamates and pyrethroids have developed resistance and resurgence. Development of resistance to neurotoxic insecticides led to restrictions in the use of these insecticides (Biddinger and Hull, 1995; Cox *et al.*, 1995). Organophosphates are very toxic to natural enemies (Bayoun *et al.*, 1995; Legaspi *et al.*, 1999) and reduced their efficiency (O'Brien *et al.*, 1985). Pest suppression using selective insecticides has been highlighted as potentially important ecosystem services of biodiversity in integrated pest management (Way and Heong, 1994; Swift and Anderson, 1994; Mooney *et al.*, 1995; Schlapfer *et al.*, 1999; Wilby and Thomas, 2002). Moreby and Southway (1999) observed higher number of bugs, spiders and beetles in untreated fields than insecticidal treatments. Agricultural intensification, including conventional use of pesticide, has resulted in biodiversity losses worldwide (Stoate *et al.*, 2001; Butler *et al.*, 2007). Liu *et al.* (2008) reported that imidacloprid affects the number and species diversity in communities of arthropods (natural enemies as spiders) strongly than the target pest in agricultural crops. Tanaka *et al.* (2000) reported

that the intensive application of broad-spectrum insecticides might cause the mortality of a wide range of natural enemies than that of target pest. Several authors have reported the toxicity of conventional insecticides to the natural enemies present in various agro-ecosystem and most of them were harmful to parasitoids and predators (Michaud and Grant, 2003; Balakrishnan *et al.*, 2009; Sahito *et al.*, 2011; Sabry and El-Sayed, 2011).

Indiscriminate pesticide use has decreased spider populations in agro-ecosystems, affecting the ability of spiders to control pest species (Reichert and Lockley, 1984; Clausen, 1990; Young and Edwards, 1990). Spiders have a very significant role to play in the ecology by being exclusively predatory (Wise, 1993) and thereby regulate insect populations. Some of the spiders show tolerance and even resistance to some pesticides (Marc *et al.*, 1999; Tanaka *et al.*, 2000). It was observed that immediately after the application of insecticides the spider population was reduced and subsequently it increased and attained a peak. Holland *et al.* (2000) reported that spiders are more sensitive to OP insecticides *viz.*, dimethoate and malathion. A decrease in spider populations as a result of pesticide use can result in an outbreak of pest populations. Agricultural fields that were frequently subjected to pesticides often had lower spider populations (Amalin *et al.*, 2001). The studies indicated that sublethal effects of dimethoate may result in an immediate disruption of predatory behaviour and a potential reduction in the efficiency of *Coccinella septempunctata* (Linnaeus) to locate and capture their prey, since chemicals may interfere with the feeding behaviour by repellent, antifeedant or reduced olfactory capacity effects (Singh *et al.*, 2001).

Natural enemies could be conserved through the use of selective insecticides at low dose. Neonicotinoids are highly specific, low-toxicity and low use rate. Legaspi *et al.* (2000) reported that novel insecticides are found to be non toxic to *Cotesia flavipes* (Cameron), braconid, *Allorhogas pyralophagus* (Marsh) and the twice-stabbed ladybird beetle, *Chilocorus cacti* (L.), while the organophosphates are highly toxic to beneficial insects. Lee and Kim (2001) showed that spider populations were not affected by insecticide applications even though there was a drop in numbers of many arthropods including insect pests. The reason is due to selectivity of insecticides to particular pest. Srinivasababu and Sharma (2003) found that imidacloprid @ 12.5 g a.i. ha⁻¹ was the safest chemical against coccinellids compared to conventional insecticides like dimethoate and

chlorpyrifos. Preetha (2007) reported that the application of imidacloprid 17.8 SL @ 25 g a.i. ha⁻¹ was found to be less toxic to natural enemies especially coccinellids and spiders. Amalin *et al.* (2009) reported that more individuals in the families Pompilidae, Scelionidae, Halictidae, Mutillidae, Apidae and Eulophidae belonging to the order Hymenoptera were collected in the non sprayed plots. Similarly more individuals of the order Orthoptera were collected in the non-sprayed area than the sprayed area. They also observed higher number of spider mites and chalk mites in the sprayed area and a higher number of armored scales, eriophyid mite, butterfly and moth larvae in the non-sprayed area. Selective insecticides had a negligible effect on natural enemies, particularly if the active ingredient is very specific. They are harmless to spiders, *Philodromus cespitum* (Walckenaer) (Araneae: Philodromidae) in terms of mortality (Rezac *et al.*, 2010). Ahmed *et al.* (2011) indicated that *Coccinella undecimpunctata* (Linnaeus) survived from residual and contact application of imidacloprid @ 100 mg a.i.l⁻¹.

Michael and Jonathan (2012) reported that arthropod abundance was significantly greater in untreated plots than the plots treated with thiamethoxam in soybean when examined as a group, but no differences were found in the abundance of natural enemy *viz.*, spiders (Araneae), harvestman, *Phalangium opilio* (L.), *Chrysoperla* sp. and coccinellid larvae and adults. Rishikumar *et al.* (2012) studied the influence of pesticides on pest and predatory arthropods associated with cotton and found that foliar application of insecticides reduced predatory arthropods like coccinellids, Chrysopids and spiders population. Sasikumar and Kumar (2012) reported that newer insecticides *viz.*, thiamethoxam 25 WG at 31.25 g a.i.ha⁻¹, imidacloprid 17.8 SL @ 22.2 g a.i. ha⁻¹ had no inhibitory effect on the population of spiders *viz.*, *Leucange decorata* (Blackwall), *Salticus* sp. and *Oxyopes javana* (Thorell) in sesame. Padmavathy and Gopalswamy (2013) reported that usage of synthetic insecticides affected the non-target arthropods order *viz.*, Collembola, Arachnida/Opiliones, Hymenoptera and Thysanoptera.

Jehan *et al.* (2013) found that, insecticide treatment in conventional fields had a significant long term effect on non targeted arthropods and short term effect on pests or insects and it started to increase 21 days after spraying. The foliar application of thiamethoxam and imidacloprid increased the soil arthropods, Collembola and decreased Psocoptera, Oribatida, Actinedida and Gamasida density when compared to the control plots.

He also found recolonization of soil arthropods in soil treated with pesticides and that follows a natural cycle. Ahmed *et al.* (2014) compared the efficacy of neonicotinoids *viz.*, nitenpyram 10 SL, thiacloprid 480 SC, imidacloprid 200 SL, acetamaprid 20 SC with traditional insecticides *viz.*, profenofos 50 EC, methidathion 40 EC, bifenthrin 10 EC and lambda cyhalothrin 2.5 EC. They reported that the newer insecticides were safer to natural enemies and toxic for the sucking pests as compared to conventional insecticides.

Latif *et al.* (2010) observed that flubendiamide and Nimbicidine[®] had no negative or harmful effect on plant dwelling predaceous arthropods in brinjal ecosystem. They reported that flubendiamide and Nimbicidine[®] were comparatively safe for natural enemies and might be fit well into the integrated pest management (IPM) programs for brinjal. Sekh *et al.* (2007) observed that flubendiamide 480 SC @ 24 and 30 g a.i. ha⁻¹ was safe to important natural enemies associated with rice leaf folder and yellow stem borer. Both classes of diamides (phthalic acid and anthranilic diamides) also exhibit very good eco-toxicological profiles, posing only small risks to beneficial insects such as parasitic wasps, ladybirds, predatory mites and pollinators at field application rates (Dinter *et al.*, 2008; Tohnishi *et al.*, 2010). Up to date individual case studies looking into impact of chlorantraniliprole on non-target organisms showed little or no effect (Larson *et al.*, 2012). However, more in-depth studies are needed of the sublethal effects, of these new insecticides, on the non-target organisms including economically important beneficial insects such as pollinators (bees and bumble bees). Jaafar *et al.* (2013) reported that chlorantraniliprole @ 0.4 l ha⁻¹ was effective in controlling the pest and at same time it had the least effects to non - target arthropods in rice ecosystem. The reasons for this were that the insecticides in the market had some level of selectivity and that rice field spiders may have developed resistance.

2.7. Computational modelling and characterization of insect ryanodine receptor

Anthranilic diamides, targets insect ryanodine receptors. These receptors regulate release of stored intracellular calcium and play a critical role in muscle contraction. As with insects, nematodes express ryanodine receptors and are sensitive to the plant alkaloid, ryanodine. However the plant parasitic nematode, *Meloidogyne incognita* (Kofoid and White) Chit, is insensitive to anthranilic diamides. Replacement of a 46

amino acid segment in a highly divergent region of the *Drosophila* C-terminus with that from *Meloidogyne* results in a functional RyRs which lack sensitivity to diamide insecticides. These findings indicate that this region is critical to diamide sensitivity in insect ryanodine receptors. Furthermore, this region may contribute to the understanding of the differential selectivity diamides exhibit for insect over mammalian ryanodine receptor (Yong *et al.*, 2013). Wang *et al.* (2012) found that CmRyRs residues N⁴⁹²², N⁴⁹²⁴, N⁴⁹³⁵, L⁴⁹⁵⁰, L⁴⁹⁸¹, N⁵⁰¹³ and T⁵⁰⁶⁴ are unique to lepidopteran RyRs compared with non-lepidopteran insect RyRs. This finding suggests that these residues may be involved in the differences in channel properties between lepidopteran and non-lepidopteran insect RyRs and in the species selective toxicity of diamide insecticides. Troczka *et al.* (2015) has given the overall level of sequence conservation between different insects.

Table 1. Comparison of RyRs protein sequences of various insects (% identity)

	<i>D. melanogaster</i>	<i>P. xylostella</i>	<i>B. mori</i>	<i>A. pisum</i>	<i>A. gambiae</i>	<i>B. tabaci</i>	<i>C. medinalis</i>	<i>S. exigua</i>	<i>A. mellifera</i>	<i>M. persicae</i>
<i>Drosophila melanogaster</i> Meigen	X	77.8	78.9	75.6	82.4	77.1	79.3	78.9	78.3	75.6
<i>Plutella xylostella</i> (Linnaeus)		X	91.2	77.0	78.5	78.7	92.0	92.1	80.7	77.1
<i>Bombyx mori</i> (Linnaeus)			X	77.7	79.6	79.3	93.8	94.6	81.7	77.8
<i>Acyrthosiphon pisum</i> (Harris)				X	76.9	82.3	78.3	78.3	79.7	99.3
<i>Anopheles gambiae</i> (Giles)					X	77.9	80.2	80.0	79.4	77.0
<i>Bemisia tabaci</i> (Gennadius)						X	79.9	79.9	82.4	82.3
<i>Cnaphalocrocis medinalis</i> (Guenee)							X	95.0	82.3	78.2
<i>Spodoptera exigua</i> (Hubner)								X	82.3	78.4
<i>Apis mellifera</i> Fabricius									X	79.6
<i>Myzus persicae</i> (Sulzer)										X

CHAPTER III MATERIALS AND METHODS

Studies were conducted to evaluate the bioefficacy of pyridine derivative 20 SC against tomato fruit borer, *Helicoverpa armigera* Hubner and American serpentine leafminer, *Liriomyza trifolii* (Burgess) in tomato, leaf folder, *Cnaphalocrocis medinalis* Guenee and yellow stem borer, *Scirpophaga incertulas* Walker in rice; its selective toxicity to beneficial and natural enemies as well as to assess the biodiversity of arthropods in tomato and rice ecosystem and molecular characterization of ryanodine receptor against target pests. The experiments conducted both under field and laboratory conditions using various methodologies are explained below in detail.

A. Field Experiments

3.1. Bioefficacy of pyridine derivative 20 SC against fruit borer and leafminer in tomato

Two field experiments were conducted to assess the bioefficacy of pyridine derivative 20 SC against fruit borer and leafminer in tomato in the farmer's holdings by adopting all standard agronomic practices. The first field experiment on tomato was laid out at Thennamanallur, Coimbatore with the tomato hybrid US 3140 during October 2013 - January 2014 and second field experiment at Mathampatti, Coimbatore with the tomato hybrid Mahalakshmi, during February – May 2014 (Plate 1).

3.1.1. Experimental details

The first and second field experiments were laid out in Randomized Block Design (RBD) with the plot sizes of 25 m² with spacing of 60 x 45 cm. The following six treatments were replicated four times.

S. No	Treatments	Dose (g a.i. ha ⁻¹)
1.	Pyridine derivative 20 SC	40
2.	Pyridine derivative 20 SC	50
3.	Pyridine derivative 20 SC	60
4.	Chlorantraniliprole 20 SC	30
5.	Novaluron 10 EC	75
6.	Untreated check	-

Two rounds of spraying were given at 15 days interval commencing from 40th days after transplanting with 500 litres of spray fluid per hectare, using hand operated knapsack sprayer.

3.1.2. Method of assessment

3.1.2.1. *Helicoverpa armigera*

Helicoverpa armigera larval population and fruit damage were recorded before spraying and 3,7,10, and 14 days after spraying. The number of larvae were recorded on five randomly selected plants per plot and the fruit damage was assessed based on number of fruits with bore holes and total number of fruits in five randomly selected plants per plot and expressed as per cent fruit damage.

3.1.2.2. *Liriomyza trifolii*

Leafminer damage per cent and live maggots were recorded from five plants selected at random per plot prior to insecticide spraying and 3, 7, 10, and 14 days after each spraying.

3.1.2.3. Natural enemies

The number of spiders and coccinellids were recorded on ten randomly selected plants per plot prior to insecticides spraying and 3, 7, 10 and 14 days after each spray and expressed as number per ten plants.

3.1.3. Yield assessment

Tomato fruit yield per plot was recorded from each harvest and pooled to arrive at the total yield and expressed as tonnes ha⁻¹ and subjected to statistical analysis. Per cent increase in yield over the control was also worked out.

3.2. Evaluation of phytotoxicity

Phytotoxicity of pyridine derivative 20 SC on tomato was evaluated in field experiments conducted at during October 2013 - January 2014 and February – May 2014 with hybrids US 3140 and Mahalakshmi in a plot size of 5m x 5m, respectively. The following treatments were replicated five times in randomised block design

S. No	Treatments	Dose (g a.i. ha ⁻¹)
1.	Pyridine derivative 20 SC	60
2.	Pyridine derivative 20 SC	120
3.	Pyridine derivative 20 SC	240
4.	Untreated check	-

3.2.1. Assessment of phytotoxicity

Symptoms of phytotoxicity *viz.*, leaf injury, wilting, vein clearing, necrosis, epinasty and hyponasty were observed on 1, 3, 5, 7, 10, 14, 21 and 28 days after treatment. The number of leaves showing these phytotoxicity symptoms were expressed in percentage and the extent of phytotoxicity was graded based on the following scale prescribed by Central Insecticide Board and Registration Committee (C.I.B and R.C).

Grade	Phytotoxicity symptom in percentage
0	No phytotoxicity symptoms
1	1-10
2	11-20
3	21-30
4	31-40
5	41-50
6	51-60
7	61-70
8	71-80
9	81-90
10	91-100

The per cent leaf injury was calculated using the formula,

$$\text{Per cent leaf injury} = \frac{\text{Total grade points}}{\text{Maximum grade} \times \text{No. of leaves observed}} \times 100$$

3.3. Bioefficacy of pyridine derivative 20 SC against leaf folder and yellow stem borer in rice

Two field experiments were conducted one at Poluvampatti (September - December 2013) and Thennamanallur (March - June, 2014) to test the efficacy of different doses of pyridine derivative 20 SC against *C. medinalis* and *S. incertulas* (Plate 2) using rice variety CO (R) 48.

3.3.1. Experiment details

Field experiments were laid out in randomized block design with six treatments and replicated four times with spacing of 20 cm x 10 cm. The details of the treatments are furnished below.

S. No	Treatments	Dose (g a.i. ha ⁻¹)
1.	Pyridine derivative 20 SC	40
2.	Pyridine derivative 20 SC	50
3.	Pyridine derivative 20 SC	60
4.	Chlorantraniliprole 20 SC	30
5.	Bifenthrin 10 EC	50
6.	Untreated check	-

Recommended agronomic practices were followed. The treatments were imposed when the pests attained economic threshold level. Three rounds of spraying were given at 15 days interval commencing from 38th day after transplanting with 500 litres of spray fluid per hectare, using hand operated knapsack sprayer.

3.3.2. Method of assessment

Observations on the insect damage were made on ten randomly selected hills per plot a day before and 7 and 14 days after treatment (DAT) for dead heart and 7, 10 and 14 DAT for leaf folder damage.

3.3.2.1. Yellow stem borer

Observations were recorded on total number of tillers and tillers showing dead heart during reproductive stage on ten randomly selected hills from each plot and per cent dead heart were worked out using the formula

$$\text{Per cent dead heart} = \frac{\text{Number of affected tillers/ ten hills}}{\text{Total number of tillers/ten hills}} \times 100$$

3.3.2.2. Leaf folder

Observations on total number of leaves and number of damaged leaves per hill were recorded on ten randomly selected hills from each plot and per cent damage was worked out using the formula.

$$\text{Per cent leaf damage} = \frac{\text{Number of damaged leaves / ten hills}}{\text{Total number of leaves / ten hills}} \times 100$$

3.3.2.3. Yield

Grain yield was recorded from each plot and expressed as tonnes ha⁻¹ and data were subjected to statistical analysis.

3.3.2.4. Natural enemies

In both the field trials, the population of natural enemies viz., spiders, rove beetles (*Paederus fuscipes* Curtis) and mirid bugs (*Cyrtorhinus lividipennis* Reuter) were also recorded to assess the safety of insecticides at ten randomly selected hills and expressed as numbers per ten hills.

3.4. Evaluation of phytotoxicity

Phytotoxicity of pyridine derivative 20 SC on rice was evaluated in field experiments conducted at Poluvampatti (September - December 2013) and Thennamanallur (March - June, 2014). The following treatments were replicated five times in randomised block design with CO (R) 48 variety in a spacing of 20 cm x 10 cm.

S.No	Treatments	Dose (g a.i.ha ⁻¹)
1.	Pyridine derivative 20 SC	60
2.	Pyridine derivative 20 SC	120
3.	Pyridine derivative 20 SC	240
4.	Untreated check	-

3.4.1. Method of assessment

The observation on phytotoxic symptoms were made as described in section 3.2.1.

3.5. Arthropod diversity in tomato and rice ecosystem

Studies were conducted on arthropod biodiversity in tomato and rice ecosystem during 2013-2014. The various methodologies followed for survey, collection of arthropods, preservation and their identification and diversity analysis are described as follows.

3.5.1. Sampling methods

To develop package of methods for quantitative sampling of arthropod communities, collections were made using four different methods *viz.*, active searching, net sweeping, pitfall trap and rubbish trap. For carrying out arthropod collection, the treated and untreated fields were divided into 100 quadrats (4 m x 4 m). Five such quadrats were chosen each at random and the entire site was covered during the sampling period.

3.5.2. Collecting devices

3.5.2.1. Active searching

Active searching was done in the early morning and evening hours. Each randomly selected quadrant was actively searched for arthropods for a period of two hours. Spiders and other wingless insects were collected by walking diagonally in the fields. Utmost care was taken while capturing them without injuring and kept in polythene bags for further studies.

3.5.2.2. Net sweeping

Flying and jumping arthropods at the ground level and under storey vegetation can be effectively collected by net sweeping. The nets used in systematic sweeping were made of thick cotton cloth with a diameter of 30 cm at the mouth and a bag length of 60 cm.

For carrying out net sweeps, the treated and untreated area was divided into 100 quadrats, measuring 4 m x 4 m each. Five such quadrats representing the field were chosen at random and the entire ground level vegetation in the chosen quadrat was covered during the sweeping. Net sweeps were done between 10 a.m. to 12 noon in ground vegetation and above one feet height from the ground. The arthropods collected from each quadrat were transferred to a bucket with a small amount of ethyl acetate to kill all the arthropods and were sorted on the same day. Soft bodied insects and spiders were later separated and preserved in vials containing 70 per cent alcohol.

3.5.2.3. Pitfall traps

This method was adopted to collect ground dwelling and nocturnal arthropods in tomato ecosystem. Pitfall traps were set out using a plastic container (15 cm height and 10 cm width) buried into the soil to a depth of 20 cm. Five pitfall traps were placed in each of five randomly chosen 4 x 4 m quadrats. In order to stop the receptacle from filling with water or leaf litter and to deter some larger predators like mice, the trap was covered with a flat stone supported by four smaller stones. Teepol (2-3 drops) mixed water was kept in the traps as trapping fluid and fluid was changed every week. The traps were placed at the rate of 25 per plot.

3.5.2.4. Rubbish traps

Rubbish traps were constructed using chicken wire mesh (45 cm length and 15 cm width), stuffed with leaf litter and made into cylindrical shape. Five rubbish traps were placed in each of five randomly chosen 4 m x 4 m quadrats. The traps were placed in the field allowing a week for arthropods to take up residence. Once in a week, these traps were removed and brought to the laboratory for arthropods collection.

3.5.3. Collection and identification of arthropods

Arthropod fauna were collected from October to December 2013 in rice ecosystem and March – May 2014 in tomato ecosystem at weekly intervals using above methods. The collected arthropods were sorted out based on taxon. Soft bodied insects and spiders were preserved in 70 per cent ethyl alcohol in glass vials. Other arthropods were card mounted or pinned. The preserved specimens were photographed using image analyser and identified based on the taxonomic characters.

All arthropod species were identified to the lowest possible taxon. Insects were identified following Lefroy (1984), Comstock (1984), Richards and Davis (1983), Ayyar (1984), Poorani (2002) and also by comparing with the specimens in the Biosystematics Laboratory, Department of Agricultural Entomology, TNAU, Coimbatore. Spiders were identified with the help of Dr. M. Ganesh Kumar, Professor of Entomology, TNAU, Coimbatore and Dr. Manju Siliwal, Research Associate, Wildlife Information Liaison Development Society, Dehradun.

3.5.4. Diversity analysis of arthropods in tomato and rice ecosystem

3.5.4.1. Alpha diversity indices

Measures of diversity are frequently seen as indicators of the well-being of any ecosystem. They also serve as a measure of the species diversity in the ecosystem. The following indices were used to assess and compare the diversity and distribution of arthropods in tomato and rice ecosystem. Species richness and diversity version ii (Pisces Conservation Ltd., www.irchouse.demon.co.uk) (Henderson, 2003) programmes were used to assess and compare the diversity of arthropods in sprayed and unsprayed tomato ecosystem and rice ecosystem.

3.5.4.1.1. Species richness

3.5.4.1.1a Fisher's alpha (Fisher *et al.*, 1943)

This presents the alpha log series parameter for each sample. This is a parametric index of diversity that indicates the abundance of species following the log series distribution.

$$\alpha x, \frac{\alpha x^2}{2}, \frac{\alpha x^3}{3}, \frac{\alpha x^n}{n}$$

Where, each term gives the number of species predicted to have 1, 2, 3, ..., n individuals in the sample.

3.5.4.1.1b. Q Statistic (Kempton and Taylor, 1976)

This presents the interquartile diversity index for each sample. It measures the interquartile slope of the cumulative abundance curve and is estimated by,

$$Q = \frac{1}{2} nR_1 + \sum nr + \frac{\frac{1}{2} nR_2}{\ln \left(\frac{R_2}{R_1} \right)}$$

where,

nr - the total number of species with abundance R

R_1 and R_2 - 25 per cent and 75 per cent quartile of the cumulative species curve

nR_1 - the number of individuals in the class where R_1 falls

nR_2 - the number of individuals in the class where R_2 falls

3.5.4.1.1c. Species number (Magurran, 1987)

This represents the total number of species in each sample.

3.5.4.1.1d. Margalef's D (Clifford and Stephenson, 1975)

Margalef's D has been a favourite index for many years.

$$D_{Mg} = \frac{(S - 1)}{\ln N}$$

where,

S - total number of species recorded

N - the total number of individuals summed overall S species

3.5.4.1.1e. Shannon diversity index (Batten, 1976)

This represents the Shannon - Weiner (also called as Weaver) diversity index for each sample and is defined as:

$$H' = \sum P_i \ln P_i$$

where

P_i - The proportion of individuals in the i^{th} species

H' - This program calculates the index using the natural logarithm

3.5.4.1.1f. Brillouin diversity index (Magurran, 1987)

The Brillouin index H is calculated as follows:

$$H = \ln N! - \sum_{i=1}^s \frac{\ln n_i!}{N}$$

where,

N - is the total number of individuals in the sample

n_i - is the number of individuals belonging to the i^{th} species and s is the species number.

3.5.4.1.2. Species Dominance indices

3.5.4.1.2a. Simpson's index (Simpson, 1949)

Simpson's index describes the probability that a second individual drawn from a population should be of the same species as the first.

$$D = \sum \frac{[N_i(N_i - 1)]}{[N_s(N_s - 1)]}$$

where,

N_i - is the number of individuals in the i^{th} species

N_s - is the total number of individuals in the sample

So, larger its value, greater the diversity. The statistic $1 - C$ gives a measure of the probability of the next encounter being from another species (Hulbert, 1971).

3.5.4.1.2b. Berger Parker diversity index (Berger and Parker, 1970)

A simple dominance measure is the Berger Parker index. The index expresses the proportional importance of the most abundant species.

$$d = \frac{N_{max}}{N}$$

where,

N_{max} - is the number of individuals in the most abundant species

N - is the number of individuals in the sample

This simple index was considered by Batten (1976) to be one of the best. It is simple measure of the numerical importance of the most abundant species.

3.5.4.1.2c. McIntosh index (McIntosh, 1967)

This index was calculated using the following formula proposed by McIntosh (1967) as

$$D = \frac{N - U}{N - \sqrt{N}}$$

where,

N is the total number of individuals in the sample

U is given by the expression,

$$U = \sqrt{\sum n_i^2}$$

Where, n_i is the number of individuals belonging to the i^{th} species and the summation is undertaken for over all species.

3.5.4.1.3. Evenness indices (Pielou, 1966)

Evenness (E) is a measure of how similar the abundances of different species or categories are in a community. When all species in a community are equally abundant, the evenness index should be maximum and decrease towards zero as the relative abundances of the species diverge away from evenness closer to zero. It indicates that most of the individuals belong to one or a few species or categories, when the evenness is close to one; it indicates that each species / category consists of the same number of individuals.

$$E = \frac{H'}{\ln(S)}$$

where,

S - Total number of species in a community

H' - prime is the number derived from the Shannon diversity index

3.5.4.1.3a. Equitability J (Magurran, 1987)

Equitability or evenness refers to the pattern of distribution of the individuals between the species. This measure of equitability (J) compares the observed Shannon-Weiner index against the distribution of individuals between the observed species which would maximize diversity. If H is the observed Shannon - Weiner index, the maximum value this could take $\log S$, where S is the total number of the species in the habitat.

Therefore the index is: $J = H / \log (S)$

3.5.4.2. Beta diversity indices

Beta diversity measures increase in species diversity along transects and is particularly applicable to the study of environmental gradients. It measures two attributes, the number of distinct habitats within a region and the replacement of species by another between disjoint parts of the same habitat. All the selected samples in the active data set will be used to calculate the indices. It is assumed that the samples are arranged in the data grid in their order of occurrence along the transect. The five indices calculated and described below are those considered by Wilson and Schmida (1984).

3.5.4.2.1. Whittaker's measure, β_w

The first and one of the most straight forward measures of beta diversity was introduced by Whittaker (1972)

$$\beta_w = S / \alpha - 1$$

Where, S = the total number of species and the average species richness of the samples

α = the average sample diversity where each sample is standard size and diversity is measured as species richness

All samples must have the same size (or sampling effort).

3.5.4.2.2. Cody Bc

Cody Bc was introduced to analyse the changes in the composition of communities along habitat gradients

$$\beta_c = g(H) + 1 (H) / 2$$

Where, g(H) is the number of species gained and l(H) the number lost moving along the transect.

3.5.4.2.3. Routledge's R, I and E

Routledge (1977) was concerned with how diversity measures can be portioned into alpha and beta components. The following three indices were derived from his work. The first measure β_R , takes overall species richness and the degree of species overlap into consideration.

$$\beta_R = S^2 / 2r + S - 1$$

Where,

S is the total species number for the transect and r is the number of species pairs overlapping distributions.

Second equation simplified for qualitative data and equal sample size

Assuming equal sample sizes,

$$\beta_r = \log(T) - [(1/T) \sum e_i \log(e_i)] - [(1/T) \sum \alpha_i \log(\alpha_i)]$$

Where,

e_i = is the number of samples along the transect in which species i is present and

α_i the species richness of sample i and T is $\sum e_i$

α = the average sample diversity where each sample is standard size

The third index β_E is the simply exponential form of β_r

The third Routledge's indices is simply

$$\beta_E = \exp(\beta_r) - 1$$

3.5.4.2.4. Wilson and Schmida's T

Wilson and Schmida (1984) proposed the sixth measure of beta diversity. This index has the same elements of species loss (l) and gain (g) that are present in Cody's measure and the standardization by average sample richness α , which is a component of Whittaker's measure

$$\beta_T = [g(H) + 1(H)] / 2\alpha$$

Where the parameters are defined as c and w based on an assessment of the essential properties of a useful index: ability to detect change, additivity and independence of sample size. Wilson and Schmida (1984) concluded this as the best.

B. Laboratory Experiments

3.6. Selective toxicity of pyridine derivative 20 SC to natural enemies

Experiments were conducted under laboratory conditions to assess the safety of pyridine derivative 20 SC to parasitoids and predators. The treatment details are given below,

S.No	Treatments	Dose (g a.i.ha ⁻¹)
1.	Pyridine derivative 20 SC	40
2.	Pyridine derivative 20 SC	50
3.	Pyridine derivative 20 SC	60
4.	Chlorantraniliprole 20 SC	30
5.	Novaluron 10 EC	75
6.	Bifenthrin 10 EC	50
7.	Untreated check	-

3.6.1. Egg parasitoid, *Trichogramma chilonis* Ishii

3.6.1.1. Mass culturing of *Corcyra cephalonica* (Stainton)

Corcyra cephalonica was reared in the laboratory as per the method described by Swamiappan (1996). The emerged *Corcyra* adults were collected in the morning and allowed inside an oviposition cage of 21 x 25 cm size, with a wire mesh bottom and lateral vents. Adults were provided with 50 per cent honey solution as food. Eggs were collected at the bottom on a black paper kept in tray and cleaned with sieves. The cleaned eggs were sprinkled over partially ground cumbu grains, at the rate of one cc per 2.5 kg of grains, fortified with ten grams of yeast in a plastic basin (45 x 30 x 10 cm) and covered with kada cloth. Care was taken to maintain the culture free of storage mites and diseases by mixing five grams of wettable sulphur 80 WP and streptomycin sulphate 0.5 per cent, respectively. The emerged adults were collected and used again for culturing both host (*C. cephalonica*) and parasitoid (*T. chilonis*). The culture was maintained at room temperature of 28 ± 2°C and relative humidity of 80 ± 5 per cent.

3.6.1.2. Mass culturing of *T. chilonis*

The egg parasitoid, *Trichogramma chilonis* mother culture was obtained from Biocontrol lab, Tamil Nadu Agricultural University, Coimbatore. *T. chilonis* was mass cultured on the eggs of *C. cephalonica* as per the method described by Prabhu (1991). Fresh *Corcyra* eggs collected in the early morning were treated under UV radiation (15 W capacity) for 20 minutes at a distance of 15 cm to prevent the hatching. These eggs were pasted on paper cards of 20 x 30 cm size having rectangles of size 7 x 2 cm and placed in polythene bags along with nucleus cards at 6:1 ratio for parasitisation.

3.6.1.3. Study on parasitisation

The bioassay method described by Jalali and Singh (1997) was adopted for *T. chilonis*. Three days old parasitised egg cards were cut into one cm² bits (eggs appearing black and plumpy) were sprayed with insecticides mentioned under section 3.6 with three replications. Distilled water alone was sprayed for untreated check. Treated egg cards were shade dried for 10 minutes and then kept inside the test tubes of 10 x 1.5 cm size (Plate 3) for observation under room temperature. Number of parasitoids emerged from each treatment was recorded after 24 h and 48 h of treatment and per cent emergence was worked out using the formula,

$$\text{Per cent emergence} = \frac{\text{No. of wasps emerged}}{\text{Total no. of eggs in one cm}^2} \times 100$$

Fresh eggs were provided to these parasitoids at 6:1 ratio and the number of parasitized eggs were recorded after 24 and 48h of treatment and the per cent parasitisation was worked out using the formula,

$$\text{Per cent parasitisation} = \frac{\text{No. of parasitized eggs}}{\text{Total no. of } \textit{Corcyra} \textit{ eggs}} \times 100$$

3.6.2. Larval parasitoid, *Bracon hebetor* Say

The larval parasitoid, *B. hebetor* was obtained from Biological Control unit, Tamil Nadu Agricultural University, Coimbatore. Bioassay method described by McCutchen and Plapp (1988) was adopted with some modifications. Insecticides as mentioned in section 3.6 were prepared using acetone and water in the ratio of 80:20.

Glass vials (Borosil®) of 30 ml capacity with one mm thickness were evenly coated with 1.0 ml of insecticide solutions and dried by placing the vials horizontally on the table and rotating them using the hand. Adult *B. hebetor* were released into the vials at the rate of 10 per vial, covered with muslin cloth and secured with a rubber band (Plate 4). After an hour of exposure, honey solution was provided as food for the adults. Mortality was recorded 24 and 48 h after treatment and per cent mortality of adults was worked out using the formula,

$$\text{Per cent mortality} = \frac{\text{No. of adults dead}}{\text{Total number of wasps released}} \times 100$$

3.6.3. Green lacewing, *Chrysoperla zastrowi sillemi* (Esben - Petersen)

3.6.3.1. Mass rearing of *C. zastrowi sillemi*

Chrysoperla zastrowi sillemi eggs and grubs were procured from Biological Control unit, Tamil Nadu Agricultural University, Coimbatore where the *C. zastrowi sillemi* was mass reared with *C. cephalonica* eggs as feed. Grubs of *C. zastrowi sillemi* were reared in galvanized iron (GI) basins (30 cm dia. x 12 cm height) at 250 grubs per basin covered with kada cloth. About 25cc eggs of *C. cephalonica* were provided as feed for the grubs per basin on alternate days. Usually after five feedings, the larvae pupated into white coloured round silken cocoon. The cocoons were collected and transferred into one litre plastic container with wire mesh window for emergence of adults.

Adults were collected and transferred to GI troughs, lined inside with brown sheets for collecting the eggs. The trough was covered with muslin cloth and was secured with the help of a rubber band and thread. Over the cloth covering, two bits of sponge (2.5 cm²) dipped in water were kept besides an artificial protein rich diet in the form of semi solid paste was smeared as food for the adults. This diet consisted one part of fructose, one part of honey and one part of Protinex® with water and made into a paste (Swamiappan, 1996). From the GI troughs, the brown paper sheets with eggs were removed and used for further culturing or hatchability test.

3.6.3.2. Selective toxicity of pyridine derivative 20 SC to the eggs of *C. zastrowi sillemi*

Experiment was conducted under laboratory conditions to assess the effect of pyridine derivative 20 SC on the eggs of *C. zastrowi sillemi*, as per the method described by Krishnamoorthy (1985). The eggs along with stalk laid on brown paper strips were sprayed with insecticides as in section 3.6 using a hand atomizer. Each treatment was replicated thrice with 10 eggs per treatment (Plate 5). Untreated check was maintained by spraying distilled water alone. Number of grubs hatched in each treatment was recorded and per cent hatchability was worked out by using the formula,

$$\text{Per cent hatchability} = \frac{\text{No. of grubs hatched}}{\text{Total number of eggs}} \times 100$$

3.6.3.3. Selective toxicity of pyridine derivative 20 SC to the grubs of *C. zastrowi sillemi* by dry film method

The bioassay method described by McCutchen and Plapp (1988) was adopted with modifications (Plate 6). Glass vials of 30 ml capacity with one millimeter thickness were evenly coated with 1.0 ml of insecticide solutions by rolling it for few seconds. Second instar lacewing grubs were released into the vials at five per vial and covered with muslin cloth secured with a rubber band. For untreated check 1.0 ml of pure acetone was used. Mortality observations were made at 12, 24 and 48 h after treatment. One cc of *C. cephalonica* eggs was given as food for the grubs at 24 h interval. Observations were recorded on per cent mortality of the grubs (24 and 48 h after treatment), pupation and adult emergence.

3.6.4. Coccinellid, *Cheilomenes sexmaculata* Fabricius

3.6.4.1. Mass culturing of Coccinellids

Coccinellid eggs collected from the cotton field were used as nucleus culture for mass multiplication under laboratory conditions (28 ± 2°C and 80 ± 5% RH). The eggs were transferred to plastic container covered with filter paper and allowed for hatching. Cowpea twigs infested with aphids were given as food for grubs and adults. Uniform size of active and healthy third instar grubs were used for bioassay.

3.6.4.2. Selective toxicity of pyridine derivative 20 SC to the grubs of *C. sexmaculata* by dry film method

Bioassay method described by McCutchen and Plapp (1988) was adopted (Plate 7). Different insecticidal concentrations as per the field dose (as in 3.6) were prepared in acetone: water (80:20). Insecticide concentrations (0.5 ml) were evenly coated in the glass vials of 30 ml capacity and dried thoroughly for 15 minutes. The third instar grubs of *C. sexmaculata* were released at the rate of five per vial and covered with muslin cloth secured by rubber band. Treatments were replicated thrice. After an hour of exposure, the grubs were transferred to test tubes and field collected aphids were given as food. Observations were made 24 and 48 h after treatment and the per cent grub mortality was worked out using the formula

$$\text{Per cent mortality} = \frac{\text{No. of grubs dead}}{\text{Total number of grubs}} \times 100$$

3.6.4.3. Selective toxicity of pyridine derivative 20 SC to *C. sexmaculata* adults

The *C. sexmaculata* adults were used for the study and the method adopted for coccinellid grub was followed for adults also (3.6.4.2.) (Plate 7).

3.7. Selective toxicity of pyridine derivative 20 SC to beneficial organisms

3.7.1. Honeybees

Safety of pyridine derivative 20 SC to honey bees, viz., Indian bee, *Apis cerana indica* F., rock bee, *Apis dorsata* F. little bee, *Apis florea* F. and Dammer bee or stingless bee, *Trigona iridipennis* Smith was assessed in the laboratory using contact toxicity method (Plate 8). The worker honey bees of above species were obtained from Apiary, Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore. The experiment was conducted with the treatments as mentioned in section 3.6 with three replications.

Different concentrations of pyridine derivative 20 SC were prepared using distilled water. Plastic containers with perforations were used for the experiment to allow adequate aeration for the bees. Filter papers of 10 cm diameter were placed inside the container, wetted with 1ml of insecticide solutions and then allowed to dry. Worker

(honey) bees were kept in refrigerator (4°C) for three minutes prior to test to calm them for easy handling. Bees were transferred at the rate of 10 to 15 per container. After an hour of exposure, the bees were transferred to polythene bags containing cotton wool dipped in 40 per cent sucrose solution as feed. The bee mortality was observed after one, 12 and 24 h of treatment and corrected per cent mortality worked out.

3.7.2. Compatibility with beneficial microorganisms

3.7.2.1. Effect of pyridine derivative 20 SC on the growth of *Trichoderma viride* (Persoon)

A laboratory experiment was conducted with six insecticidal treatments viz., pyridine derivative 20 SC @ 400, 500 and 600 ppm, chlorantraniliprole 20 SC (300 ppm), novaluron 10 EC (1500 ppm) and bifenthrin 10 EC (1000 ppm) which were equivalent to field doses along with untreated check. Each treatment was replicated thrice to study the effect on the growth of *T. viride* under *in vivo* conditions by following poisoned food technique. The culture was obtained from Biocontrol unit, Department of Plant Pathology, TNAU, Coimbatore. Test insecticides were prepared as per field doses and mixed in 50 ml of sterilized potato dextrose agar (PDA) medium under aseptic condition. PDA medium alone served as control. The treated media were poured to sterilized petridishes under aseptic condition and allowed to solidify. After solidification, 5 days old *T. viride* of 8 mm diameter disc was inoculated to the centre of the plate using inoculation needle under aseptic condition and the plates were incubated at 32 ±2°C in an incubator. The radial growth of *T. viride* was observed after 24, 48 and 72 hours after inoculation (HAI).

3.7.2.2. Effect of pyridine derivative 20 SC on *Pseudomonas fluorescens* (Migula)

King's B agar medium (50 ml) was amended to obtain final concentrations of treatments as mentioned in 3.6. *Pseudomonas fluorescens* broth culture obtained from Biocontrol, Department of Plant Pathology, TNAU, Coimbatore was inoculated on the amended broth under aseptic condition and 20 ml was transferred to each petridish incubated for 72 h at 32 ±2°C while unamended medium served as control. The plates were observed for *P. fluorescens* growth at 24, 48 and 72 HAI.

3.7.2.3. Effect of pyridine derivative 20 SC on *Beauveria bassiana* (Balsamo)

The test insecticide was mixed in 200 ml sterilized molten PDA medium to obtain final concentration as mentioned in 3.6. and the plating was done aseptically.

After solidification, the plates were inoculated with 5 mm dia mycelial disc of 7 days old *B. bassiana* culture obtained from Department of Plant Pathology, Coimbatore and the plates were incubated at $26 \pm 2^\circ\text{C}$ for 10 days to observe the colony diameter. Plates with PDA medium alone served as control.

3.8. Statistical analysis

The per cent reduction of pests over control in the field population was worked out using the formula

$$\text{Per cent reduction over control} = \frac{C - T}{C} \times 100$$

where,

- T - Number of insects in the treatment
 C - Number of insects in the untreated check

The data on insect numbers were transformed into $\sqrt{x+0.5}$ values and percentage into arc sine $\sqrt{\text{per cent}}$ values before statistical analysis. The data from laboratory experiments were analysed in completely randomized block design (CRBD), while the same from field experiments were analysed in randomized block design (RBD) (Gomez and Gomez, 1984). The mean values were separated using Duncan's Multiple Range Test (DMRT) (Duncan, 1951).

The mortality data in laboratory studies were corrected by using Abbot's (Abbott, 1925) formula,

$$\text{Per cent corrected mortality} = \frac{\text{Per cent test mortality} - \text{per cent control mortality}}{(100 - \text{per cent control mortality})} \times 100$$

3.9. Computation modelling and characterization of insect ryanodine receptor

3.9.1. Construction of phylogenetic tree and comparison of protein structure

The RyR sequences of different insect species for construction of phylogenetic tree were downloaded from GeneBank (<http://www.ncbi.nlm.nih.gov/Genbank/index.html>). The GeneBank accession numbers are as follows: *Bactrocera dorsalis* (Hendel)

(BdRyR), KJ082086.1, XM_011213800.1; *Bactrocera cucurbitae* (Coquillett), XM_011195435.1, XM_011195439.1, XM_011195441.1, XM_011195442.1, XM_011195443.1, XM_011195446.1, XM_011195449.1, XM_011195450.1, XM_011195437.1, XM_011195440.1, XM_011195443.1, XM_011195448.1, XM_011195452.1, XM_011195438.1, XM_011195445.1, XM_011195451.1, XP_011193744.1; *Chilo suppressalis* (Walker), JX082287.1, KP213290.2, JQ 769305.1, KJ573635.1; *C. medinalis*, JQ799046.1, JQ769302.1, *H. armigera*, KF641862.1, KJ573634.1, AHB33498.1; *Plutella xylostella* (Linnaeus), JF926693.1, JF926694.1, NM 001309134.1, JQ769303.1, JN801028.1, NM001309073.1, NF927788.1; *Sogatella furcifera* (Horvath), KJ573636.1, KF306296.1, AIA23859.1; *Nilaparvata lugens* (Stal), KJ573638.1, KF734669.1; *Tribolium castaneum* (Herbst), XM_008193108.1, KM216386.1, AIU40166.1; *Apis mellifera* Linnaeus, XM_006569024.1, XM_006569030.1, XM_006569043.1, XM_006569044.1, XM_006569046.1, XM_006569029.1, XM_006569033.1, XM_006569035.1, XM_006569036.1, XM_006569037.1, XM_006569038.1, XM_006569040.1, XM_006569041.1, XM_006569042.1, XM_006569045.1, XM_006569047.1, XM_006569034.1, XM_006569039.1, XM_392217.5, XP_006569093.1. The phylogenetic tree was constructed on the basis of amino acid sequences by the software Geneious. Similarly, ryanodine receptor sequence of *Drosophila melanogaster* Meigen [UniProt ID: Q24498] was retrieved from Uniprot database [<http://www.uniprot.org/>]. The transmembrane segment of the protein was modeled using SWISS-MODEL (<http://swissmodel.expasy.org/>). The structural alignment and superimposition were carried out using Accelrys Discovery Studio 2.5.

CHAPTER IV

EXPERIMENTAL RESULTS

The results of the experiments conducted to evaluate the bioefficacy, safety and phytotoxicity of pyridine derivative 20 SC on tomato and rice, selective toxicity to natural enemies, compatibility with microorganisms and molecular characterization of ryanodine receptor in the target pests under laboratory conditions are presented in this chapter.

4.1. Field experiment on tomato I- Thennamanallur village

4.1.1. Bioefficacy of pyridine derivative 20 SC against tomato fruit borer, *Helicoverpa armigera* Hubner and serpentine leafminer, *Liriomyza trifolii* (Burgess)

4.1.1.1. Fruit damage

Fruit damage before imposing the treatments ranged from 11.22 to 12.65 per cent and found to be non-significant (Table 2). After first spray, pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ significantly reduced fruit damage and were on par with each other at 3,7,10 and 14 days after treatment (DAT). Pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ recorded the lowest fruit damage of 7.09 per cent at 7 DAT followed by its lower doses pyridine derivative 20 SC @ 50 and 40 g a.i. ha⁻¹ which recorded 7.50 and 8.16 per cent, respectively. The standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and novaluron 10 EC @ 75 g a.i. ha⁻¹ recorded fruit damage of 9.22 and 10.01 per cent, respectively.

After second application, similar trend in the reduction of fruit damage was observed. At 7 DAT, pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ recorded 5.79 and 6.94 per cent, respectively and they were on par with its lower dose 40 g a.i. ha⁻¹ (7.90 %). The standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and novaluron 10 EC @ 75 g a.i. ha⁻¹ recorded 8.68 and 10.04 per cent fruit damage, respectively, while the untreated check recorded 21.88 per cent fruit damage (Table 2).

After two rounds of foliar sprays, based on the per cent reduction in fruit damage over untreated check, the order of efficacy of different insecticidal treatments is as follows: pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (58.88 %) > pyridine derivative

20 SC @ 50 g a.i. ha⁻¹ (54.13 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (50.12 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (44.10 %) > novaluron 10 EC @ 75 g a.i. ha⁻¹ (42.28 %) (Table 2).

4.1.1.2. *H. armigera* larval population

Population of *H. armigera* larvae before imposing the insecticidal treatments ranged from 8.40 to 9.40 five plants⁻¹ and was non-significant (Table 3). At 7 DAT after first spray, pyridine derivative 20 SC at test doses viz., 60 and 50 g a.i. ha⁻¹ recorded the lowest larval population of 0.20 and 0.40 five plants⁻¹, respectively. It was followed by its lower dose @ 40 g a.i. ha⁻¹ (1.00 five plants⁻¹), standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (1.20 five plants⁻¹) and novaluron 10 EC @ 75 g a.i. ha⁻¹ (2.60 five plants⁻¹). The untreated check recorded the population of 12.20 five plants⁻¹.

After second application, no larval population was found in pyridine derivative 20 SC 60 and 50 g a.i. ha⁻¹ at 7 DAT. It was followed by its lower dose @ 40 g a.i. ha⁻¹ and chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ which gave same extent of reduction in larval population (0.20 five plants⁻¹). The highest larval population was recorded in untreated check (12.00 five plants⁻¹). After two rounds of spray, based on the mean per cent reduction of *H. armigera* population, the order of efficacy of different insecticidal treatments is as follows: pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (94.60 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (91.82 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (87.54 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (85.60 %) > novaluron 10 EC @ 75 g a.i. ha⁻¹ (72.96 %).

4.1.1.3. Serpentine leafminer *L. trifolii*

4.1.1.3. a. Leaf damage.

Prior to application the per cent leaf mining ranged from 30.54 to 31.25 per cent plant⁻¹ and was non significant (Table 4). Pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ recorded leaf damage of 25.86 and 27.34 per cent, respectively at 10 DAT after first spray, whereas that in lower dose @ 40 g a.i. ha⁻¹ (28.04 %) was less when compared to the standard checks, chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (29.42 %), novaluron 10 EC @ 75 g a.i. ha⁻¹ (28.75 %) and untreated check (34.55 %).

At 7 DAT after second spray also, the trend in reduction of leaf damage among the treatments was similar to the first spray (Table 4). All the treatments of pyridine derivative 20 SC @ 60 - 40 g a.i. ha⁻¹ recorded the lowest leaf damage ranged between 24.73 and 27.85 per cent at 14 DAT and it was followed by the standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (29.50 %), novaluron 10 EC @ 75 g a.i. ha⁻¹ (29.06 %) and untreated check (39.74 %). After two sprays based on the per cent reduction in leaf mining over untreated check, the order of efficacy of different insecticidal treatments is as follows: pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (27.45 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (23.45 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (20.34 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (16.95 %) > novaluron 10 EC @ 75 g a.i. ha⁻¹ (17.41%).

4.1.1.3. b. *Liriomyza trifolii* maggot population

The population of leafminer before insecticidal application was uniform ranging from 7.70 to 8.55 plant⁻¹ among the experimental plots and was non-significant (Table 5). Pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ was significantly superior over other treatments with a mean population of 1.05 and 1.60 plant⁻¹, respectively at 7 DAT after first spray. It was followed by pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (2.25 plant⁻¹) and chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (2.50 plant⁻¹) and novaluron 10 EC @ 75 g a.i. ha⁻¹ (3.20 plant⁻¹) with slight reduction of maggot population. A steady increase in leafminer population was observed in untreated plot throughout the experiment (9.05 plant⁻¹).

After second spray, similar trend in population reduction was noticed among the treatments. After 7 days after treatment, the highest reduction of leafminer population was recorded in pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (0.60 plant⁻¹) followed by its lower dose @ 50 g a.i. ha⁻¹ (0.95 plant⁻¹), while the untreated check recorded the highest leafminer population of 10.10 plant⁻¹. After two rounds of spraying, based on the per cent reduction in leafminer population over untreated check, the order of efficacy of different insecticidal treatments is as follows: Pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (88.31 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (83.52 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (77.78 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (76.44 %) > novaluron 10 EC @ 75 g a.i. ha⁻¹ (66.42 %).

4.1.2. Effect of pyridine derivative 20 SC on natural enemies in tomato

4.1.2.1. Coccinellids

The coccinellid population prior to treatment ranged from 5.50 to 6.25 ten plants⁻¹. At 3 DAT after first spray, decrease in coccinellid population was observed among the treated plots. Reduction in the coccinellid population was found to be indirectly proportional to the pyridine derivative 20 SC test doses. Pyridine derivative 20 SC at the highest dose of 60 g a.i. ha⁻¹ was found to be slightly toxic which recorded 2.25 coccinellids ten plants⁻¹ and was followed by its lower doses 50 and 40 g a.i. ha⁻¹ which recorded 3.00 and 3.50 coccinellids ten plants⁻¹ at 7 DAT, respectively (Table 6). The standard checks viz., novaluron 10 EC @ 75 g a.i. ha⁻¹ (2.75 coccinellids ten plants⁻¹), chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (3.00 coccinellids ten plants⁻¹) recorded the less population and the untreated check recorded the highest of 6.75 coccinellids ten plants⁻¹ after first spray. However, recovery of coccinellid population was observed thereafter and pyridine derivative 20 SC @ 60, 50 and 40 g a.i. ha⁻¹ recorded coccinellid population in the range of 2.50 to 4.25 coccinellids ten plants⁻¹ at 10 and 14 DAT. Untreated check recorded the highest population of 7.25 and 6.25 coccinellids ten plants⁻¹ at 10 and 14 DAT, respectively.

After second spray, trend in coccinellid population was similar to the first spray. At 14 DAT, pyridine derivative 20 SC @ 50 and 40 g a.i. ha⁻¹ was relatively safe and recorded spider population of 4.50 and 4.75 coccinellids ten plants⁻¹, respectively and it was on par with the standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and novaluron 10 EC @ 75 g a.i. ha⁻¹ (3.75 and 3.75 coccinellids ten plants⁻¹, respectively). The untreated check recorded the highest population of 7.00 coccinellids ten plants⁻¹.

4.1.2.2. Spiders

The spider population prior to treatments ranged from 8.25 to 9.00 ten plants⁻¹ (Table 7). At 3 DAT after first spray, decrease in spider population was observed among the treated plots and it was dose dependent. Pyridine derivative 20 SC at the highest dose of 60 g a.i. ha⁻¹ was more toxic which recorded 4.25 spiders ten plants⁻¹ and was followed by its lower doses 50 and 40 g a.i. ha⁻¹ which recorded 4.75 and 6.75 spiders ten plants⁻¹, respectively at 3 DAT after first spray. Spider population in standard checks

chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹, novaluron 10 EC @ 75 g a.i. ha⁻¹ recorded 3.00 and 4.50 spiders ten plants⁻¹, respectively, while the untreated check recorded the highest of 9.00 spiders ten plants⁻¹. Spider population recovered gradually at 10 and 14 DAT after first spray, pyridine derivative 20 SC @ 60, 50 and 40 g a.i. ha⁻¹ recorded in the range of 4.75 to 7.00 spiders ten plants⁻¹.

After second spray, trend in the reduction of the spider population three days after application and subsequent recovery was similar to the first spray. After two rounds of spraying, pyridine derivative 20 SC at lower doses of 50 and 40 g a.i. ha⁻¹ was relatively safe and recorded pooled mean spider population of 5.75 and 6.29 spiders ten plants⁻¹, respectively compared to the highest in untreated check (8.38 spiders ten plants⁻¹).

4.2. Field experiment on tomato II- Mathampatti

4.2.1. Bioefficacy of pyridine derivative 20 SC.

4.2.1.1. Fruit damage

The data on fruit damage by *H. armigera* during first round of application, at pretreatment and post treatment intervals of 3, 7, 10 and 14 days are presented in Table 8. The fruit damage before application of treatments ranged from 12.23 to 13.98 per cent and there was no significant difference among the treatments. After first spray, pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ significantly reduced fruit damage levels and were on par with each other at 3, 7, 10 and 14 DAT. Pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ recorded the lowest fruit damage of 8.50 per cent at 7 DAT and it was on par with its lower dose 50 g a.i. ha⁻¹ (9.04 %). The lowest dose of pyridine derivative @ 40 g a.i. ha⁻¹ recorded 10.16 per cent followed by standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (10.56 %) and novaluron 10 EC @ 75 g a.i. ha⁻¹ (10.74 %). The untreated check recorded the highest damage per cent of 16.97. The mean damage was also the lowest in 60 g a.i. ha⁻¹ (9.85 %) compared to the untreated check (17.45 %).

After second application, similar trend in the reduction of fruit borer damage was observed. The overall mean of fruit damage ranged from 8.40 to 19.25 per cent. After two sprayings at 15 days interval, based on the per cent reduction in fruit borer damage over untreated check, the order of efficacy of different insecticidal treatments is as follows:

pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (56.35 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (51.44 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (47.38 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (43.92 %) > novaluron 10 EC @ 75 g a.i. ha⁻¹ (43.83 %) (Table 8).

4.2.1.2. *Helicoverpa armigera* larval population

It was revealed from Table 9 that there was no significant differences in the pre-application count of fruit borer larval population between treatments as well as control. At 7 days after treatment, the lowest numbers of *H. armigera* larvae were recorded in plots treated with pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (0.20 five plants⁻¹) followed by its lower doses 50 and 40 g a.i. ha⁻¹ which recorded 0.60 and 1.00 five plants⁻¹, respectively, while the standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and novaluron 10 EC @ 75 g a.i. ha⁻¹ recorded 1.40 and 2.40 five plants⁻¹, respectively. The untreated check recorded 4.80 larvae five plants⁻¹. A steady increase in the *H. armigera* population was observed in untreated control throughout the experimental period.

During second spraying, three days after treatment nil population of *H. armigera* was recorded in the treatments pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹. Whereas its lower dose @ 40 g a.i. ha⁻¹ recorded minimum population of 0.40 five plants⁻¹ followed by the standard check chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (0.80 five plants⁻¹). After two sprayings at 15 days interval, based on the per cent reduction in fruit borer larval population over untreated check, the order of efficacy of different insecticidal treatments is as follows; pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (94.20 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (86.96 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (76.81 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (74.40 %) > novaluron 10 EC @ 75 g a.i. ha⁻¹ (53.14 %) (Table 9).

4.2.1.3. Serpentine leafminer *L. trifolii*

4.2.1.3. a. Leaf damage.

The leaf damage recorded from insecticide treatments against serpentine leafminer are presented in Table 10. The leaf damage ranged between 33.33 and 35.85 per cent. The highest incidence of 38.27 per cent of leaf damage was recorded in untreated check as against 31.74 per cent in pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ treated plot at

10 DAT, indicating its superiority over other treatments in suppressing the pest damage. It was followed by its lower doses 50 and 40 g a.i. ha⁻¹ recording 32.67 and 33.68 per cent leaf damage, respectively. The standard checks viz., chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and novaluron 10 EC @ 75 g a.i. ha⁻¹ recorded 34.22 and 33.12 per cent, respectively at 10 days after treatment.

Similar trend persisted even after second spray. After application of second spray, pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ retained the minimum leaf damage of 31.58 and 32.48 per cent mean damage, respectively. Based on the per cent reduction in leaf damage over untreated check, the order of efficacy of different insecticidal treatments is as follows; pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (19.14 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (17.00 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (14.98 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (14.64 %) > novaluron 10 EC @ 75 g a.i. ha⁻¹ (14.27 %) (Table 10).

4.2.1.3. b. *Liriomyza trifolii* maggot population

The pre treatment count revealed no significant variation as regards to the number of serpentine leafminer maggots plant⁻¹, indicating uniform distribution of the pest throughout the experimental plots initially. After imposing the treatments, superiority of pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ was significantly envisaged with record of the lowest number of maggots plant⁻¹ (1.90 and 2.45, respectively) at 7 days after treatment in comparison with other treatments viz., pyridine derivative 20 SC @ 40 g a.i. ha⁻¹, chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and novaluron 10 EC @ 75 g a.i. ha⁻¹ registering 2.80, 2.85 and 3.70 plant⁻¹, respectively. The highest maggot population was recorded in untreated check (9.45 plant⁻¹) (Table 11).

After two rounds of spraying, similar trend was observed. Based on the per cent reduction in leafminer population over untreated check, the order of efficacy of different insecticidal treatments is as follows; pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (83.32 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (78.33 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (75.02 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (73.08 %) > novaluron 10 EC @ 75 g a.i. ha⁻¹ (66.33 %) (Table 11).

4.2.2. Effect of pyridine derivative 20 SC on natural enemies in tomato

4.2.2.1. Coccinellids

The coccinellid population prior to treatment ranged from 5.25 to 6.00 ten plants⁻¹. At 3 DAT after first spray, decrease in coccinellid population was observed among the treated plots. Marginal reduction in the population was observed at 3 DAT after first spray in the insecticide treated plots. Pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ was relatively toxic to coccinellids (2.50 coccinellids ten plants⁻¹) and its lower doses @ 50 and 40 g a.i. ha⁻¹ were relatively less toxic (3.25 and 4.75 coccinellids ten plants⁻¹, respectively). Recovery of population was evident from the data recorded at 7, 10 and 14 DAT, which was in the range of 3.00 to 4.50 coccinellids ten plants⁻¹ in pyridine derivative 20 SC treated plots (Table 12).

At 10 DAT after second spray, pyridine derivative 20 SC @ 50 and 40 g a.i. ha⁻¹ was relatively less toxic (Table 12). After two rounds of spraying based on the mean population of coccinellids, the order of relative safety of different insecticides is as follows; pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (4.19 coccinellids ten plants⁻¹) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (3.56 coccinellids ten plants⁻¹) > novaluron 10 EC @ 75 g a.i. ha⁻¹ (3.38 coccinellids ten plants⁻¹) > pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (3.03 coccinellids ten plants⁻¹) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (2.78 coccinellids ten plants⁻¹) (Table 12).

4.2.2.2. Spiders

The pretreatment population of spiders ranged from 8.25 to 9.25 ten plants⁻¹ and was non-significant (Table 13). At 3 DAT, decrease in spider population was observed among the treated plots. Reduction in the spider population was observed in all the insecticidal treatments. However on the 14 DAT, the spider population revived quickly in pyridine derivative 20 SC treatments @ 60, 50 and 40 g a.i. ha⁻¹ which recorded 5.75, 6.25 and 6.00 spiders ten plants⁻¹, respectively.

Similar trend was noticed after second spray also. After two rounds of spraying based on the overall mean of spider population, the order of relative safety of different insecticides is as follows; pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (6.13 spiders ten plants⁻¹) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (5.35 spiders ten plants⁻¹) > pyridine derivative

20 SC @ 60 g a.i. ha⁻¹ (5.19 spiders ten plants⁻¹) > novaluron 10 EC @ 75 g a.i. ha⁻¹ (4.82 spiders ten plants⁻¹) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (4.16 spiders ten plants⁻¹). The highest mean population of spider was recorded in the untreated check (9.79 spiders ten plants⁻¹) (Table 13).

4.3. Tomato yield

4.3.1. Yield -I season

Pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ was effective in increasing the yield and recorded 38.08 and 37.35 t ha⁻¹, respectively and were on par. It was followed by its lower dose 40 g a.i. ha⁻¹ (35.06 t ha⁻¹), standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (33.69 t ha⁻¹) and novaluron 10 EC @ 75 g a.i. ha⁻¹ (32.50 t ha⁻¹). Untreated check recorded the lowest of 28.57 t ha⁻¹ (Table 14).

4.3.2. Yield-II season

Pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ was superior during second season also recording 42.20 and 41.49 t ha⁻¹, respectively followed by its lower dose 40 g a.i. ha⁻¹ (38.85 t ha⁻¹), standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (38.45 t ha⁻¹) and novaluron 10 EC @ 75 g a.i. ha⁻¹ (36.30 t ha⁻¹). Untreated check recorded the lowest tomato yield of 31.08 t ha⁻¹ (Table 14).

4.4. Phytotoxic effect of pyridine derivative 20 SC on tomato

The data on phytotoxic effect of pyridine derivative 20 SC on hybrid tomato, carried out at Thennamanallur and Mathampatti are presented in Table 15. The results revealed that pyridine derivative 20 SC sprayed on tomato crop at 60 (x), 120 (2x) and 240 (4x) g a.i. ha⁻¹ showed no phytotoxic symptoms like leaf tip injury, wilting, vein clearing, necrosis, epinasty or hyponasty.

4.5. Field experiment on rice I- Poluvampatti

4.5.1. Bioefficacy of pyridine derivative 20 SC against rice yellow stem borer and leaf folder

4.5.1.1. Yellow stem borer damage

The results revealed that all the doses of pyridine derivative 20 SC recorded with significant reduction in the dead heart damage caused by stem borer (Table 16). The stem

borer damage before imposing treatment ranged from 10.05 to 10.64 per cent. At 7 DAT, the lowest damage was recorded in plots sprayed with pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (7.67 %) and pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (8.33 %) followed by pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (9.00 %) and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (9.00 %). Based on the mean damage after first spray, pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ recorded the lowest mean damage of 7.81 and 8.43 per cent, respectively. It was followed by chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (8.90 %), pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (9.06 %) and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (9.09 %) whereas the untreated check recorded 10.30 per cent (Table 16).

After second round of spraying, pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ registered minimum damage of 6.75 and 7.25 per cent, respectively at 7 DAT and were found to be on par. Pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ and chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ recorded 7.75 and 8.00 per cent, respectively. The highest damage among the insecticidal treatments was registered in bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (8.50 %) next to the untreated check (10.00 %) (Table 16).

After three rounds of spraying, based on the per cent reduction in dead heart damage over untreated check, the order of efficacy of different insecticidal treatments is as follows; pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (54.68 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (52.03 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (45.00 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (39.07 %) > bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (34.78 %) (Table 17).

4.5.1.2. Leaf folder damage

The results of the field experiment carried out at Poluvampatti are presented in Tables 18 and 19. The pretreatment damage caused by leaf folder varied from 10.38 to 12.31 per cent. Among the insecticidal treatments, the lowest leaf damage was observed in pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ treated plots which recorded 9.06 and 9.59 per cent, respectively at 10 DAT. It was followed by the lower dose of pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (9.93 %), the standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (10.20 %) and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (10.71 %) (Table 18).

After second spray, pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹ recorded the lowest mean damage of 8.23 and 8.89 per cent, respectively followed by its lower dose 40 g a.i. ha⁻¹ which recorded 9.17 per cent damage. The standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ recorded 9.53 and 10.06 mean per cent damage. The untreated check recorded 12.57 per cent damage (Table 18).

After three rounds of spraying, significant reduction in leaf folder damage was observed in all the insecticide treatments and the order of efficacy of different treatments over untreated check is as follows; pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (40.72 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (35.74 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (32.85 %) ≥ chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (32.85 %) > bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (26.59 %) (Table 19).

4.5.2. Effect of pyridine derivative 20 SC on natural enemies in rice.

4.5.2.1. Spiders

The pretreatment population of spiders ranged from 6.50 to 7.25 ten hills⁻¹. Among the chemicals tested, pyridine derivative 20 SC @ 60, 50 and 40 g a.i. ha⁻¹ was the least toxic recording a mean of 4.50, 5.00 and 5.00 spiders ten hills⁻¹, respectively at 7 DAT (Table 20) whereas, the standard checks *viz.*, chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ recorded 4.00 and 3.75 spiders ten hills⁻¹, respectively.

At the time of second application, similar trend was noticed. After second spray, pyridine derivative 20 SC @ 40 and 50 g a.i. ha⁻¹ recorded mean spider population of 4.81 and 4.63 ten hills⁻¹, respectively. Pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ recorded 4.19 spiders ten hills⁻¹ and the standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ recorded 3.94 and 3.56 spiders ten hills⁻¹, respectively (Table 20).

After three rounds of spray, the highest pooled mean population of spiders was recorded in untreated check (6.94 ten hills⁻¹). Among the chemicals tested, plots treated with pyridine derivative 20 SC @ 40 and 50 g a.i. ha⁻¹ harboured mean spider population of 4.58 and 4.36 ten hills⁻¹, respectively, whereas the higher dose 60 g a.i. ha⁻¹ harboured mean population of 3.98 spiders ten hills⁻¹ (Table 21).

4.5.2.2. Mirids

Mirid population prior to spraying was non-significant among the treatments in the range of 5.00 to 6.00 ten hills⁻¹ (Table 22). Marginal reduction in the population was observed at 3 DAT among the treated plots. Pyridine derivative 20 SC at higher doses of 60 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ were relatively toxic (2.75 and 2.50 mirids ten hills⁻¹), while the lower doses of pyridine derivative 20 SC @ 50 and 40 g a.i. ha⁻¹ were relatively less toxic (3.50 mirids ten hills⁻¹) next to the untreated check (4.75 mirids ten hills⁻¹). Recovery of mirid population was evident at 7, 10 and 14 DAT, which was in the range of 3.50 to 4.75 ten hills⁻¹ in pyridine derivative 20 SC treated plots (Table 22).

At 10 DAT after second spray, pyridine derivative 20 SC @ 50 and 40 g a.i. ha⁻¹ was relatively less toxic and recorded 3.25 and 3.75 mirids ten hills⁻¹, respectively (Table 22). After three rounds of spraying based on the pooled mean reduction of mirids, the order of relative safety of different insecticides is as follows; pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (3.83 ten hills⁻¹) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (3.46 ten hills⁻¹) > pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (3.15 ten hills⁻¹) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (3.11 ten hills⁻¹) > bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (2.52 ten hills⁻¹). The highest mean population of spiders was recorded in the untreated check (6.21 ten hills⁻¹) (Table 23).

4.5.2.3. Rove beetle

The pretreatment population of rove beetle ranged from 8.50 to 9.50 ten hills⁻¹ and was non-significant (Table 24). Marginal reduction in the population was observed 3 DAT after first spray in the insecticide treated plots. However after 14 DAT, rove beetle population recovered and it was in the range of 7.00 to 7.75 ten hills⁻¹ in pyridine derivative 20 SC test doses compared to the highest in untreated control (9.50 ten plants⁻¹). Similar recovery was noticed after second spray also. At 10 DAT, pyridine derivative 20 SC at lower doses of 50 and 40 g a.i. ha⁻¹ were relatively safe and recorded 5.75 and 6.00 beetles ten hills⁻¹, respectively, while it was 7.25 beetles ten plants⁻¹ in untreated check.

After three rounds of spray, the order of treatments, in terms of safety to rove beetles as follows; pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (5.92 ten hills⁻¹) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (5.36 ten hills⁻¹) > pyridine derivative 20 SC @ 60 g a.i. ha⁻¹

(5.04 ten hills⁻¹) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (4.52 ten hills⁻¹) > bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (4.29 ten hills⁻¹). The highest mean population of rove beetle was recorded in the untreated check (7.79 ten hills⁻¹) (Table 25).

4.6. Field experiment on rice II- Thennamanallur

4.6.1. Bioefficacy of pyridine derivative 20 SC against rice stem borer and leaf folder

4.6.1.1. Stem borer damage

At the time of application of treatments, dead hearts caused by stem borer ranged from 10.72 to 11.12 per cent (Table 26). At 7 DAT, the lowest dead heart damage was recorded in plots treated with pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (8.21 %) followed by pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (8.93 %) and chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (9.29 %). On 14 DAT, pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ recorded the lowest dead heart damage of 7.50 per cent followed by pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (8.75 %) and chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (9.38 %). The untreated check recorded 11.88 per cent damage.

After second round of spraying, pyridine derivative 20 SC @ 60, 50 and 40 g a.i. ha⁻¹ recorded dead heart damage of 5.95, 7.15 and 8.10 per cent, respectively on 14 DAT effecting 42.23, 31.64 and 23.45 per cent reduction over control, respectively (Table 26). The standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ effected 23.63 and 17.66 per cent reduction over control, respectively.

After three sprayings, similar trend was observed. Based on the per cent reduction in dead heart damage over untreated check, the order of efficacy of different insecticidal treatments is as follows; pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (52.80 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (47.79 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (33.17 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (30.27 %) > bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (24.44 %) (Table 27).

4.6.1.2. Leaf folder damage

Damage caused by leaf folder varied from 10.15 to 10.75 per cent prior to the treatments (Table 28). On 10 DAT, pyridine derivative 20 SC @ 60 and 50 g a.i. ha⁻¹

recorded significantly the leaf damage of 8.94 and 9.08 per cent, respectively followed by its lower dose 40 g a.i. ha⁻¹ (9.26 %). Pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ recorded 14.95 per cent reduction over control followed by its lower doses 50 and 40 g a.i. ha⁻¹ (13.95 and 12.22 %, respectively) whereas the standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ recorded 10.76 and 11.85 per cent, respectively.

At 14 days after second spray, pyridine derivative 20 SC @ 60, 50 and 40 g a.i. ha⁻¹ recorded 8.03, 8.45 and 8.68 per cent damage, respectively and effected correspondingly 25.18, 21.85 and 19.87 per cent reduction over control (Table 28) and was superior to other treatments. After three sprayings, similar trend was observed. Based on the per cent reduction in leaf folder damage over untreated check, the order of efficacy of different insecticidal treatments is as follows; pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (31.25 %) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (26.90 %) > pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (24.46 %) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (23.01 %) > bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (21.83 %) (Table 29).

4.6.2. Effect of pyridine derivative 20 SC on natural enemies in rice.

4.6.2.1. Spiders

The pretreatment population of spiders ranged from 7.75 to 8.50 ten hills⁻¹. After first round of spraying, at 3 DAT, decrease in spider population was observed among the treated plots. Reduction in the spider population was found to be proportional to the pyridine derivative 20 SC test doses. Pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ recorded 3.75 spiders ten hills⁻¹ at 3 DAT while the lower doses 50 and 40 g a.i. ha⁻¹ recorded 4.00 and 4.50 spiders ten hills⁻¹, respectively and found to be on par with each other (Table 30). The standard checks *viz.*, chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (3.50 spiders ten hills⁻¹), bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (2.75 spiders ten hills⁻¹) recorded less spider population, while the untreated check recorded the highest of 7.50 spiders ten hills⁻¹ at 3 DAT after first spray. But at 14 DAT after first spray, population of spiders slowly recovered and the population in pyridine derivative 20 SC @ 60, 50 and 40 g a.i. ha⁻¹ was 5.75, 6.50 and 6.50 spiders ten hills⁻¹, respectively, whereas the untreated check recorded the highest spider population (8.50 ten hills⁻¹) (Table 30).

After second spray, similar trend was observed. At 14 DAT, pyridine derivative 20 SC treatments viz., 60, 50 and 40 g a.i. ha⁻¹ recorded 6.50, 6.75 and 7.25 spiders ten hills⁻¹, respectively. After three rounds of spraying, pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ recorded the highest mean spider population (4.75 ten hills⁻¹) among the insecticide treated plots. It was followed by its higher doses 50 and 60 g a.i. ha⁻¹ which recorded 4.38 and 4.13 spiders ten hills⁻¹, respectively (Table 31). Minimum population of spiders was recorded in standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (3.81 and 3.56 ten hills⁻¹, respectively) when compared to the untreated check (8.25 ten hills⁻¹).

4.6.2.2. Mirids

The population of mirids was uniform (6.00 to 6.50 ten hills⁻¹) in the rice crop prior to commencement of insecticidal treatment. Among the insecticide treatments, mean population of mirid bug was the highest in the treatment sprayed with pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (4.44 ten hills⁻¹) followed by pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (4.25 ten hills⁻¹) and pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (3.94 ten hills⁻¹) (Table 32). The least population of mirids was recorded in the standard checks, chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (3.31 ten hills⁻¹) and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (3.00 ten hills⁻¹).

After second spray, based on the mean population of mirids, untreated check recorded the highest of 7.69 ten hills⁻¹, followed by pyridine derivative 20 SC @ 40, 50 and 60 g a.i. ha⁻¹ (3.88, 3.63 and 3.44 ten hills⁻¹, respectively), the standard checks chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (3.13 ten hills⁻¹) and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (2.69 ten hills⁻¹).

After three rounds of spraying, the mean population of mirids was higher in untreated check (7.75 ten hills⁻¹). Among the insecticidal treatments, pyridine derivative 20 SC @ 40 and 50 g a.i. ha⁻¹ recorded the highest mean mirid population of 3.50 and 3.06 ten hills⁻¹ followed by 60 g a.i. ha⁻¹ (2.88 ten hills⁻¹), chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (2.75 ten hills⁻¹) and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (2.25 ten hills⁻¹) (Table 33). The pooled mean of three rounds of applications showed the lowest mirid numbers in bifenthrin 10 EC (2.65 ten hills⁻¹) and higher in pyridine derivative 20 SC (3.42 to 3.94 ten hills⁻¹).

4.6.2.3. Rove beetle.

The pretreatment population of rove beetle ranged from 7.25 to 8.25 ten hills⁻¹ in different treatments. After the first spraying, reduction in population was observed at 3 DAT in all insecticidal treatments and recovery of rove beetle population was found in 7, 10 and 14 DAT. The mean population of rove beetles was higher in untreated check (8.56 ten hills⁻¹). Pyridine derivative 20 SC @ 40, 50 and 60 g a.i. ha⁻¹ recorded 6.50, 6.06 and 5.56 beetles ten hills⁻¹, respectively followed by chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (5.50 beetles ten hills⁻¹) and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (4.81 beetles ten hills⁻¹) (Table 34). Similar recovery was noticed after second spray and at 10 DAT, pyridine derivative 20 SC at lower doses of 40 and 50 g a.i. ha⁻¹ were relatively safe and recorded 6.00 and 5.75 beetles ten hills⁻¹ compared to 8.75 beetles ten hills⁻¹ observed in untreated check (Table 34).

After three sprays, based on pooled mean of three sprays, the order of insecticidal treatments, in terms of safety to rove beetle is as follows; pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (5.92 ten hills⁻¹) > pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (5.50 ten hills⁻¹) > pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ (5.10 ten hills⁻¹) > chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (4.96 ten hills⁻¹) > bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (4.46 ten hills⁻¹). The untreated check recorded the highest population of 8.75 ten hills⁻¹ (Table 35).

4.7.1. Yield – I season

Significant reduction in stem borer and leaf folder damage in the plots treated with pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ had resulted in higher grain yield (4.92 t ha⁻¹) with 54.44 per cent increase over untreated check followed by pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (4.69 t ha⁻¹), pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ (4.27 t ha⁻¹), chlorantraniliprole 20 SC @ 30 a.i. ha⁻¹ (3.92 t ha⁻¹) and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (3.83 t ha⁻¹) as against 3.18 t ha⁻¹ in untreated check (Table 36).

4.7.2. Yield – II season

Pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ recorded the highest grain yield of 4.30 t ha⁻¹ with an increase of 58.34 per cent over untreated check followed by pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (3.98 t ha⁻¹), pyridine derivative 20 SC @ 40 g a.i. ha⁻¹

(3.62 t ha⁻¹), chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (3.46 t ha⁻¹) and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (3.31 t ha⁻¹) effecting 46.82, 33.46, 27.56 and 21.84 per cent increase over untreated check, respectively (Table 36).

4.8. Phytotoxic effect of pyridine derivative 20 SC on rice

The data on phytotoxicity of pyridine derivative 20 SC on rice varieties, carried out at Poluvampatti and Thennamanallur are presented in Table 37. The results revealed that pyridine derivative 20 SC sprayed on rice crop at 60 (x), 120 (2x) and 240 (4x) g a.i. ha⁻¹ exhibited no phytotoxic symptoms like leaf tip injury, wilting, vein clearing, necrosis, epinasty or hyponasty.

4.9. Collection and identification of arthropods in tomato and rice ecosystems.

4.9.1. Diversity of arthropods in tomato ecosystem

Arthropods collected at weekly intervals from November 2013 to January 2014 in sprayed and unsprayed tomato fields were documented, identified to the possible taxonomic level (Order, Family, Genus or Species) and various biodiversity indices were worked out. A total of 2760 individuals belonging to 14 orders and 48 families were collected from tomato ecosystem (Table 38).

4.9.1.1. Insecta

The Class Insecta was the most common followed by Arachnida. Under Insecta, exopterygotes were the largest group represented by seven orders viz., Orthoptera, Dictyoptera, Odonata, Hemiptera, Isoptera, Dermaptera and Thysanoptera. While endopterygotes were represented by five orders viz., Diptera, Hymenoptera, Lepidoptera, Coleoptera and Neuroptera.

Among exopterygotes, maximum individuals were recorded in the order Hemiptera (781) followed by Orthoptera (127), Thysanoptera (85), Odonata (22), Dermaptera (18) and Dictyoptera (11). Under Hemiptera, the most dominant family was Aphididae represented by single species *Aphis gossypii* Glover. The other taxonomically important families were; Cicadellidae, Aleyrodidae, Pentatomidae, Miridae, Anthocoridae, Membracidae, Coreidae, Meenoplidae, Lygaeidae and Delphacidae. In case of Aphididae, 136 individuals of *A. gossypii* were recorded in unsprayed tomato and 72 in sprayed field. Orthoptera was

represented by five families viz., Pyrgomorphidae (*Atractomorpha similis* Bolivar), Acrididae (*Trilophidia annulata* Thunberg and unidentified sp.), Gryllidae (*Gryllus* sp.), Tettigonidae (*Phaneroptera gracilis* Burmeister) and Tridactylidae (*Tridactylus* sp.) with majority of individuals from unsprayed tomato field (Table 38).

Among endopterygotes, maximum individuals were recorded in the Order Diptera (458) followed by Hymenoptera (435), Coleoptera (417), Lepidoptera (182) and Neuroptera (12). Among the four families of Hymenoptera collected, majority of the individuals were from Formicidae followed by Apidae, Vespidae and Megachilidae. Order Coleoptera was represented by six families with majority of individuals belonging to Coccinellidae (181) in both sprayed and unsprayed field. *Cheilomenes sexmaculata* Fabricius (163) was the more dominant species under the family Coccinellidae. Next to Coccinellidae, Curculionidae was the most important with majority of species being *Mylocherus* sp. (122). Neuroptera was represented by single family Chrysopidae with single species *Chrysoperla zastrowi sillemi* (Esben - Petersen) (12). Under order Lepidoptera maximum number of individuals belonged to family Noctuidae (131), followed by Nymphalidae (26) and Lycaenidae (12).

The overall data revealed that the predatory arthropods viz., Coccinellids and Green lace wing, *C. zastrowi sillemi* were higher in the unsprayed fields compared to sprayed fields. Similarly, *A. similis*, *Tridactylus* sp. (Orthoptera), *Oxyctonia versicolor* Fabricius, *Aulacophora foveicollis* Lucas and *Alphitobius* sp. (Coleoptera) were greater in numbers in unsprayed plots, but no differences were found in the abundance of insects in the plots treated with pyridine derivative 20 SC (Table 38).

4.9.1.2. Arachnida

Spiders belonging to ten species and nine genera were recorded. Family Lycosidae (49) was dominant followed by Araneidae (43), Tetragnathidae (22), Oxyopidae (19), Salticidae (17) and two unidentified species. Family Lycosidae was represented by two species viz., *Pardosa birmanica* Simon and *Pardosa* sp. Under Araneidae majority of the species collected were *Neoscona theisi* Walckenaer (23). *Peucetia viridana* Hentz (19) was the most species collected under family Oxyopidae.

Family Tetranychidae was represented by *Tetranychus urticae* Koch species (25) in both sprayed and unsprayed tomato fields. The overall data revealed that the number of spiders collected was higher in untreated plots (111) compared to the treated plots (66) (Table 38).

4.9.1.3. Biodiversity indices

4.9.1.3.1. Alpha diversity indices at ordinal, family, generic and species level

The arthropods collected were identified to order, family, genus and species level (Plates 9 to 14). Based on the data, different indices were calculated

4.9.1.3.1.a. Species richness indices

Based on calculated familial level, species number was minimum (31) during the last week of December and maximum (37) during the second month of November in sprayed tomato. Similarly in the unsprayed tomato, value was maximum in November and minimum during the last week of December. Based on generic and species level, species number was maximum in the month of November and minimum in the month of December (Table 39).

Based on generic and species level, the Fisher's alpha index values were the lowest in the first week of December and maximum in the second week of November in the sprayed field, whereas in unsprayed field it was minimum in the last week of December and maximum in the first week of November (Table 40).

Q statistic value based on familial level ranged from 9.9414 to 18.034 in sprayed and 12.837 to 20.025 in unsprayed tomato fields and showed significant variation (Table 41). Minimum variation was observed with Margalef's D and Shannon - Weiner indices based on ordinal, generic, familial and species level between the sprayed and unsprayed tomato fields (Tables 42 and 43).

Analysis of data using Brillouin diversity index is presented in Table 44. Based on generic level, the index value varied between a minimum of 2.6895 during the third week of December and maximum of 3.0044 during second week of November in sprayed tomato. In unsprayed tomato, the index value was the highest during the second week of November (3.1678) and the lowest during the last week of December (2.7912).

4.9.1.3.1.b. Species dominance indices

Analysis of data based on Simpson's index, at familial level the value was maximum (25.134 and 22.77) during second week of November in sprayed and unsprayed tomato fields (Table 45). Berger Parker diversity index was calculated based on the four taxonomic levels. No variation was observed in ordinal, familial, generic level and species level in sprayed and unsprayed tomato fields, respectively (Table 46).

McIntosh index indicated clear variation in the values at familial level, the maximum was noticed on second week of November (0.86347) in sprayed tomato field, and in unsprayed field (0.84151) (Table 47). Equitability J index showed that at generic level, the value was maximum (0.85478 and 0.86174) during the second week of November in both sprayed and unsprayed field, respectively. (Table 48).

From the above indices, it is inferred that maximum number of arthropods was recorded in unsprayed tomato fields than the sprayed fields. Maximum diversity of arthropods was observed during the month of November and minimum during the month of December with most of the diversity indices.

4.9.1.4. Beta diversity indices at ordinal, family, generic and species level

In the current study, Beta diversity indices viz., Whittaker's Bw, Cody Bc, Routledge's Br, Routledge's Bi, Routledge's Be and Wilson and Schmida's Bt indices were used to compare the species compositions of different communities in both sprayed and unsprayed tomato fields. According to Whittaker's Bw the value was higher in sprayed field (0.2844) and lower in unsprayed field (0.22807) at ordinal level. Based on familial, generic level and species level all the indices value were higher in the sprayed field than the unsprayed field (Table 49).

4.9.2. Diversity of arthropods in rice ecosystem

Arthropods collected at weekly intervals from October to December (2014) for four weeks in rice field were documented, identified to the possible taxonomic level (Order, Family, Genus or Species) and various biodiversity indices were worked out. The survey yielded a wide array of 90 species under 84 genera belonged to 54 families and 11 orders (Table 50 and Plates 15 to 23).

Table 50 shows that totally 5,095 arthropods were collected of which maximum number of individuals belonged to Class Insecta (4653) and Arachnida (442).

4.9.2.1. Insecta

Under Insecta, majority of individuals belonged to the division Exopterygota followed by Endopterygota (Table 50).

4.9.2.1.a. Exopterygota

The Exopterygota (2856) were represented by Orthoptera, Mantodea, Odonata, Hemiptera and Dermaptera, among which hemipterans were the most abundant (Table 47). Totally 10 families of Hemiptera were collected with the majority of individuals fall under the family Cicadellidae (791) followed by Delphacidae (514), Pentatomidae (303), Alydidae (274), Gerridae (133), Miridae (110), Meenoplidae (82), Reduviidae (65), Lophopidae (12) and Coreidae (11).

Cicadellidae was represented by five genera with majority of individuals from the genus *Nephotettix virescens* Distant (247) followed by *Recilia dorsalis* (Motschulsky) (192). Under the family Delphacidae, *Nilaparvata lugens* Stal (322) was dominant. Similarly, *Pygomenida varipennis* Westwood (146) was dominant insects under the family Pentatomidae. Under the order Orthoptera, Acrididae (44) was the dominant family followed by Gryllidae (24). Acrididae was represented by the genus *Oxya* asp.

Under Odonata, Coenagrionidae (216) was the dominant family followed by Libellulidae (193). *Agriocnemis rubricauda* Tillyard (156) was the most common species collected under the family Coenagrionidae. *Orthetrum sabina* (Drury) (72) was dominant under the family Libellulidae. Under the order Mantodea, 6 individuals of *Mantidae* sp. was collected. The order Dermaptera was represented by single individual species of earwig (32) (Table 50).

4.9.2.1.b. Endopterygota

Endopterygota was represented by five orders viz., Diptera, Hymenoptera, Lepidoptera, Coleoptera and Neuroptera of which Hymenoptera was the most dominant order (Table 50).

Hymenoptera was represented by six families. Maximum number of individuals were collected under the family Formicidae (551), followed by Apidae (104), Vespidae (41), Ichneumonidae (37), Crabronidae (10) and Braconidae (6). The majority of individuals from Formicidae were represented by the genus *Solenopsis geminate* Fabricius (322) (Table 50). Genus *Apis* was dominant under the family Apidae. Totally six families of Lepidoptera were collected. The greatest number of individuals were collected under the family Crambidae (272) followed by Hesperidae (122) and Pyralidae (94). Only one individual was found in Noctuidae (Table 50). Among the lepidopterans, except *Otheris* sp. all the species were found throughout the study period.

Coleoptera was represented by eight families with maximum number of individuals collected belonging to the family Chrysomelidae (141) followed by Coccinellidae (103), Staphylinidae (61) and Carabidae (50). Family Curculionidae and Melyridae were represented by *Myllocerus* sp. (15) and *Apalochrus* sp. (6), respectively. Individuals of families Elateridae and Lampyridae were less in number.

Dipterans were represented by six families viz., Stratiomyidae (74) and Tipulidae (27). *Hedriodiscus* sp (74) was dominant in the family Stratiomyidae. Order Neuroptera was represented by a single family Myrmeleontidae (4) represented by the genus *Myrmeleon* sp.

4.9.2.2. Arachnida

A total of 18 species of spiders from nine families were recorded. The majority of families represented under order Araneae belonged to Tetragnathidae (125) followed by Lycosidae (100), Oxyopidae (65), Araneidae (58), Clubionidae (28), Salticidae (21) and unidentified sp. (21). Minor families recorded were Thomisidae (19) and Philodromidae (5) (Table 50).

Family Tetragnathidae was represented by three species viz., *Tetragnatha javana*, *Tetragnatha* sp. and *Tylorida striata* Thorell. Majority of the genus collected were *Tetragnatha* (97). Lycosidae was represented by *Lycosa* sp., *Pardosa* sp., *Pardosa birmanica* Simon, *Hippasa* sp. and unidentified sp. with majority of individuals from *Hippasa* (26). *Oxyopes javanus* Thorell (30) was found abundant in the family Oxyopidae. Under Araneidae, majority of the species recorded was *Argiope* sp. (32) and *Neoscona* sp. (26) (Table 50).

4.9.2.3. Biodiversity indices

4.9.2.3.1. Alpha diversity indices at ordinal, family, generic and species level

4.9.2.3.1.a. Species richness indices

Based on the calculated ordinal and familial level (Table 51), numbers in sprayed field was maximum in the first week of December (10 and 43, respectively) and minimum in the month of November (9 and 36, respectively). The ordinal, familial, generic and species level numbers in unsprayed field was minimum in the third week of November (9, 39, 64 and 69, respectively) and maximum in the first week of October (11, 51, 80 and 87, respectively).

Based on generic and species level analysis, the Fishers alpha index value was the highest during the first week of October (30.615 and 35.03, respectively) and the value was minimum in the second week of November (23.342 and 26.191, respectively) in sprayed field. In unsprayed field, it was minimum in last week of November (19.898 and 21.4448, respectively) and maximum in first week of October (32.576 and 37.302, respectively) (Table 52).

From Table 53 it could be seen that the Q statistic value based on familial level varied between a minimum of 10.82 during the third week of November and maximum of 15.533 in the first week of October in sprayed rice. In unsprayed rice field, the index value was the highest during the first week of October (16.11) and the lowest during the last week of November (10.563).

Analysis of data using Margalef's D is presented in Table 54. The index value based on ordinal and familial recorded no significant variance in both sprayed and unsprayed rice field. On the generic level, the value was maximum in the first week of October (11.605) and minimum in the second week of November (9.9867) in sprayed rice. In unsprayed rice, the value was the highest in the first week of October (13.506) and the lowest in the last week of November (9.7447). The Shannon –Weiner index calculated based on the four taxonomic level are presented in Table 55. The index value based on ordinal, generic, familial and species in sprayed rice was equal to unsprayed field.

Brillouin diversity index (Table 56) showed minimum variation in the index value on analysis based on ordinal, generic, familial and species level between the sprayed and unsprayed rice.

The Simpson's index calculated based on ordinal level revealed maximum during the third week of October (4.3999) and minimum during December (3.0378) in sprayed rice. In unsprayed rice, the minimum was during the last week of November (3.1392) and maximum during December (4.3897) (Table 57).

Berger Parker diversity index was calculated based on the four taxonomic levels. The index value was higher in unsprayed rice than sprayed field (Table 58). McIntosh index also showed no clear variation in index values on the four taxonomic levels in both sprayed and unsprayed rice (Table 59).

Evenness indices (Equitability) also observed clear variation in the values of familial level: the maximum (0.79232) in sprayed and (0.82385) unsprayed was noticed on first week of October (Table 60).

4.9.2.3.1.b. Beta diversity indices at ordinal, family, generic and species level

In Beta diversity indices, according to Whittaker's Bw the value was higher in sprayed field (0.33333) and lower in unsprayed field (0.24297) at familial level. Based on ordinal, generic level and species level all the indices value were higher in the sprayed field than the unsprayed field (Table 61).

The maximum number of arthropods was observed in unsprayed rice than sprayed field. The maximum diversity of arthropods occurred in the month of October with most of the diversity indices.

B. Laboratory Experiments

4.10. Safety studies

4.10.1. Effect of pyridine derivative 20 SC to *Trichogramma chilonis* Ishii

4.10.1.1. Effect on adult emergence

The data presented in the Table 62 depicted the level of emergence of *T. chilonis* adults as influenced by different treatments. The level of adult emergence was considered

as basis for measuring the safety of pyridine derivative 20 SC at varied concentrations to *T. chilonis*. Pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ was found to be safe to the immature stages of *T. chilonis* by recording significantly higher adult emergence (55.00 %). This was however found to be on par with novaluron 10 EC @ 75 g a.i. ha⁻¹ (49.00 %). Pyridine derivative 20 SC at higher doses viz., 50 and 60 g a.i. ha⁻¹ recorded 46.67 and 41.00 per cent adult emergence, respectively. The highest per cent adult emergence was noticed in untreated check (64.00 %) (Table 62).

4.10.1.2. Effect on parasitisation

The insecticides had significant impact on the parasitisation efficiency of *T. chilonis*. Pyridine derivative 20 SC @ 40, 50 and 60 g a.i. ha⁻¹ was comparatively safe and recorded 82.67, 79.67 and 76.33 per cent parasitisation, respectively. The standard checks novaluron 10 EC @ 75 g a.i. ha⁻¹, chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ recorded 80.33, 71.67 and 67.00 per cent parasitisation, respectively (Table 62).

4.10.2. Effect of pyridine derivative 20 SC to larval parasitoid, *Bracon hebetor* Say

The mortality data of newly emerged adults of *B. hebetor*, observed at 24 and 48 hours after treatment with different insecticides at different dose rates are presented in Table 63. All the insecticide gave moderate mortality of adult parasitoid as compared to the untreated check. The highest dose of pyridine derivative 20 SC (60 g a.i. ha⁻¹) caused 43.33 per cent mortality at 24 hours after treatment (HAT) and 56.67 per cent mortality at 48 HAT. The doses of pyridine derivative 20 SC 50 and 40 g a.i. ha⁻¹ recorded 26.67 and 16.67 and 36.67 and 23.33 per cent mortality at 24 and 48 HAT, respectively.

4.10.3. Effect of pyridine derivative 20 SC to *C. zastrowi sillemi*

4.10.3.1. Eggs

Among the different treatments, pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ recorded maximum egg hatching of 83.22 per cent followed by pyridine derivative 20 SC @ 50 and 60 g a.i. ha⁻¹ which caused 79.91 and 79.05 per cent egg hatching and were on par with the standard checks novaluron 10 EC @ 75 g a.i. ha⁻¹ (91.17 %) and chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (73.64 %). Bifenthrin 10 EC @ 75 g a.i. ha⁻¹ caused the least hatching (68.05 %), while the untreated control recorded 96.49 per cent hatching (Table 64).

4.10.3.2. Grub

The results on the effect of pyridine derivative 20 SC on *C. zastrowi sillemi* grubs revealed that maximum grub mortality was obtained when the grubs were exposed to bifenthrin 10 EC @ 50 g a.i. ha⁻¹ and pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ with mortality of 23.33, 23.33 and 30.00, 26.67 per cent at 24 and 48 HAT, respectively. Minimum mortality was registered in the treatment pyridine derivative 20 SC @ 50 and 40 g a.i. ha⁻¹ at 24 and 48 HAT (10.00 and 3.33 and 10.00 and 10.00 per cent, respectively). No mortality was observed in untreated check (Table 65).

Pyridine derivative 20 SC @ 40 and 50 g a.i. ha⁻¹ recorded 86.67 and 83.33 and 83.33 and 76.67 per cent pupation and adult emergence, respectively. Pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ recorded 73.33 per cent pupation and 66.67 per cent adult emergence. Untreated control recorded 100 per cent pupation and adult emergence. The lowest pupation and adult emergence were recorded in novaluron 10 EC @ 75 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (76.67 and 73.33 and 70.00 and 60.00 per cent, respectively) (Table 65).

4.10.4. Effect of pyridine derivative 20 SC to coccinellids, *Cheilomenes sexmaculata* (Fabricius)

4.10.4.1. Grubs

The results from the Table 66 indicated that maximum mortality of 63.33 and 76.67 per cent was observed in bifenthrin 10 EC @ 50 g a.i. ha⁻¹ at 24 and 48 HAT, respectively. Whereas the test chemical pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ caused minimum mortality of 43.33 and 53.33 per cent at 24 and 48 HAT, respectively. Pyridine derivative 20 SC @ 50 and 60 g a.i. ha⁻¹ showed moderate toxicity of 50.00 and 50.00 and 63.33, 66.67 per cent at 24 and 48 HAT, respectively. The standard check novaluron 10 EC @ 75 g a.i. ha⁻¹ recorded 36.67 and 46.67 per cent mortality at 24 and 48 HAT, respectively (Table 66).

4.10.4.2. Adults

The data revealed that pyridine derivative @ 40 g a.i. ha⁻¹ significantly registered low mortality of 23.33 and 33.33 per cent at 24 and 48 HAT, respectively. However the

standard check novaluron 10 EC @ 75 g a.i. ha⁻¹ has recorded 16.67 and 26.67 per cent mortality at 24 and 48 HAT, respectively. The highest mortality was observed in bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (50.00 and 70.00 %) at 24 and 48 HAT. Pyridine derivative 20 SC @ 50 and 60 g a.i. ha⁻¹ recorded 30.00 and 36.67 per cent mortality in 24 HAT, respectively. It could be seen from the data obtained that pyridine derivative 20 SC @ 40 and 50 g a.i. ha⁻¹ was found to be relatively less toxic to both grubs and adults (Tables 66 and 67).

4.10.5. Effect of pyridine derivative 20 SC to honey bees

All the doses of pyridine derivative caused statistically significant mortality to four species of honeybees.

4.10.5.1. Dammer bee, *Trigona iridipennis* Smith.

Contact toxicity of pyridine derivative to dammer bees, *Trigona iridipennis* Smith showed that pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ registered less than 50 per cent mortality (16.67, 20.00 and 30.00 %) at one, 12 and 24 HAT, respectively. It was followed by pyridine derivative 20 SC @ 50 and 60 g a.i. ha⁻¹ registering mortality of less than 50 per cent at 24 HAT. Maximum mortality was recorded when the bees were exposed to bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (36.67, 43.33 and 63.33 %) at one, 12 and 24 HAT, respectively (Table 68).

4.10.5.2. Little bee, *Apis florea* Fabricius.

All the treatments caused less than 50 per cent mortality when *A. florea* was exposed for one hour. Pyridine derivative 20 SC @ 40, 50 and 60 g a.i. ha⁻¹ recorded 46.26, 51.52 and 57.78 per cent mortality at 24 HAT, respectively. The highest mortality of 60.48 per cent was recorded in bifenthrin 10 EC @ 50 g a.i. ha⁻¹ at 24 HAT. The standard checks novaluron 10 EC @ 75 g a.i. ha⁻¹ and chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ recorded 36.67 and 48.18 per cent mortality at 24 HAT, respectively (Table 69).

4.10.5.3. Rock bee, *Apis dorsata* Fabricius.

Maximum mortality of *A. dorsata* was observed in bifenthrin 10 EC @ 50 g a.i. ha⁻¹ (40.00, 50.00 and 63.33 %) followed by chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (36.67, 43.33 and 53.33 %) at one, 12 and 24 HAT, respectively. Mortality increased as the time

of exposure increased from one to 24 hours. Pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ recorded 16.67, 26.67 and 36.67 per cent and 50 g a.i. ha⁻¹ recorded 30.00, 40.00 and 46.67 per cent mortality at one, 12 and 24 HAT, respectively (Table 70).

4.10.5.4. Indian bee, *Apis cerana indica* Fabricius.

Pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ recorded 11.20, 20.32 and 41.11 per cent mortality at one, 12 and 24 HAT, respectively. It was found to be least toxic followed by its higher doses 50 and 60 g a.i. ha⁻¹ which recorded a mortality of less than 50 per cent at 24 HAT. Maximum mortality of 66.27 and 63.49 per cent was observed in bifenthrin 10 EC @ 50 g a.i. ha⁻¹ and chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ at 24 HAT, respectively. The standard check novaluron 10 EC @ 75 g a.i. ha⁻¹ recorded 8.93, 22.41 and 29.44 per cent mortality at one, 12 and 24 HAT, respectively (Table 71).

4.10.6. Compatibility of pyridine derivative 20 SC with beneficial microorganisms

4.10.6.1. *Trichoderma viride* Persoon

The radial growth of *T. viride* at various doses of pyridine derivative 20 SC was studied along with the standard check and the results are presented in Table 72. Pyridine derivative 20 SC @ 40 g a.i. ha⁻¹ recorded 22.67 mm growth at 24 hours after treatment (HAT) and was on par with pyridine derivative 20 SC @ 50 g a.i. ha⁻¹ (19.50 mm) whereas the higher dose of pyridine derivative 20 SC (60 g a.i. ha⁻¹) inhibited the radial growth (16.83 mm) which was on par with the standard check chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (13.67 mm) and all the treatments were found to have greater impact on the growth of *T. viride* when compared to untreated check.

4.10.6.2. *Pseudomonas fluorescens* Migula

The influence of pyridine derivative and other insecticides viz., chlorantraniliprole, novaluron and bifenthrin on the growth of *P. fluorescens* was studied under the laboratory conditions by using streak plate technique. The results of the experiment revealed that pyridine derivative at all the doses did not inhibit growth of the *P. fluorescens* (Table 73). The bacterial growth was uniform in all the doses of pyridine derivative tested.

4.10.6.3. *Beauveria bassiana* Balsamo

The radial growth of *B. bassiana* in pyridine derivative 20 SC @ 40 and 50 g a.i. ha⁻¹ was 8.23, 6.83 and 12.61, 9.33 mm after 5 and 10 days after inoculation (DAI), respectively (Table 74). The radial growth of pyridine derivative 20 SC @ 60 g a.i. ha⁻¹ recorded 5.67 and 7.00 mm which was on par with the standard check chlorantraniliprole 20 SC @ 30 g a.i. ha⁻¹ (3.73 and 5.33 mm) at 5 and 10 DAI, respectively. Untreated check recorded 13.67 and 18.50 mm at 5 and 10 DAI, respectively. The growth of *B. bassiana* in novaluron 10 EC @ 75 g a.i. ha⁻¹ and bifenthrin 10 EC @ 50 g a.i. ha⁻¹ was recorded as 2.77, 2.40 and 4.50, 4.23 mm at 5 and 10 DAI, respectively.

4.11. Computation modelling and characterization of insect ryanodine receptor

Root mean square deviation (RMSD) is the average distance between the atoms (the backbone atoms) of superimposed proteins, which shows the similarity in three dimensional structure. Smaller the deviation, the spatial equivalent between two proteins are more. Table 75 shows the variation in transmembrane region of different insect proteins viz., *H. armigera*, *Apis mellifera* Linnaeus, *Tribolium castaneum* (Herbst), *Bactrocera cucurbitae* (Coquillett) and *Sogatella furcifera* (Horvath). If the RMSD value between two proteins is more than 0.5 Å, the variation in protein structure is high. In this context, the RMSD value of all the protein combinations are more than 0.5 Å. The RMSD value of *A. mellifera* with *H. armigera*, *T. castaneum*, *B. cucurbitae* and *S. furcifera* was 8.544 Å, 7.103 Å, 8.319 Å and 11.948 Å.